United States
Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

Total Maximum Daily Loads (TMDLs) for Dissolved Oxygen and Iron in the Waters of Duck Creek in Mendenhall Valley, Alaska

In compliance with the provisions of the Clean Water Act, 33 U.S.C. §1251 et seq., as amended by the Water Quality Act of 1987, Public Law 100-4, the Environmental Protection Agency is establishing Total Maximum Daily Loads (TMDLs) that will result in an increase in dissolved oxygen and a decrease in elevated iron in Duck Creek to comply with the designated use and water quality criteria in Alaska's water quality standards.

These TMDLs will become effective immediately. Subsequent actions must be consistent with these TMDLs.

Signed this 15th day of October 2001.

Signed by

____

Randall F. Smith
Director
Office of Water

United States
Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

Total Maximum Daily Loads (TMDLs) for Dissolved Oxygen and Iron in the Waters of Duck Creek in Mendenhall Valley, Alaska

October 2001

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Total Maximum Daily Loads for

Dissolved Oxygen and Iron

in the Waters of Duck Creek in Mendenhall Valley, Alaska

TMDLs AT A GLANCE:

Water Quality-limited?	Yes
Hydrologic Unit Code:	19010301
Criteria of Concern:	Dissolved oxygen and iron (both impairments are addressed through control of iron loading)
Designated Uses Affected:	Water supply, water recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife
Environmental Indicators:	Dissolved oxygen monitoring and mats of iron floc
Major Source(s):	Groundwater and dissolved ferrous iron from glaciomarine sediments
Loading Capacity:	0.27 tons/yr iron (loading capacity is established for both iron and DO impairments)
Wasteload Allocation:	No point sources; wasteload allocation set to zero
Load Allocation:	0.27 tons/yr iron
Margin of Safety:	Implicit MOS included through conservative assumptions

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Executive Summary

Duck Creek is listed on the 1998 303(d) list of impaired waters in Alaska for metals (iron) and low dissolved oxygen. The primary source of iron in the creek is groundwater inflow. Much of the Mendenhall Valley is underlain by iron-rich glaciomarine deposits. As the watershed has become more developed, channel modifications and land disturbances near the creek, including the removal of the thick layer of peat that previously filtered out much of the iron, have become more common. The primary cause of low dissolved oxygen in Duck Creek is the increased influx of iron, which becomes oxidized and forms iron floc when the groundwater flows into the creek. Because the dissolved oxygen and iron impairments are related, reductions in the inflow of iron-rich groundwater to the creek will result in attainment of the dissolved oxygen criteria. Therefore, both the iron TMDL and the DO TMDL are represented by the loading capacity established for iron. The water quality standard for dissolved oxygen and the oxygen demand

exerted by dissolved iron set the loading capacity for iron at 0.27 tons/yr to protect designated uses, representing a 93 percent reduction in current loading. The Duck Creek Watershed Management Plan recommended a restoration approach which would include capping sources of iron with organic fill, planting riparian/aquatic plants capable of oxidizing iron, mechanically aerating the water at sources of dissolved iron, and increasing the volume of flow to dilute the dissolved iron.

Overview

Section 303(d)(1)(C) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 CFR Part 130) require the establishment of a Total Maximum Daily Load (TMDL) for the achievement of state water quality standards when a waterbody is water quality-limited. A TMDL identifies the degree of pollution control needed to maintain compliance with standards and includes an appropriate margin of safety. The focus of the TMDL is reduction of pollutant inputs to a level (or "load") that fully supports the designated uses of a given waterbody. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices and/or effluent limits and monitoring required through National Pollutant Discharge Elimination System (NPDES) permits.

The state of Alaska identified Duck Creek as being water quality-limited because of low dissolved oxygen, excess debris, metals (iron), fecal coliform, and turbidity (ADEC, 1998). EPA completed the TMDL for turbidity in December of 1999, the TMDL for debris in September 2000, and the TMDL for fecal coliform bacteria in December 2000 (EPA, 1999, 2000a, 2000b). This document establishes TMDLs to address the dissolved oxygen and iron impairments to the creek.

General Background

Duck Creek is located near Juneau, Alaska, in the Mendenhall Valley, a watershed that drains several streams into one of only a few major estuarine wetlands in Southeast Alaska (Figure 1). The Duck Creek watershed drains runoff and groundwater primarily from the floor of this large glacial valley. Duck Creek is a small stream of just over 3 miles in length that flows south through the middle of the heavily populated valley and enters the Mendenhall River and Mendenhall Wetlands State Game Refuge directly upstream of the Juneau International Airport runway. The creek is an anadromous fish stream (Alaska Department of Fish and Game Catalog No. 111-59-10500-2002) that historically supported runs of coho, pink, chum, and sockeye salmon. Based on descriptions from early residents, the creek originally had numerous beaver ponds and clear water that flowed year-round. Currently, the creek varies from about 5 to 15 feet in width and from a few inches to several feet in depth. Duck Creek has two main tributaries–East Fork and El Camino.

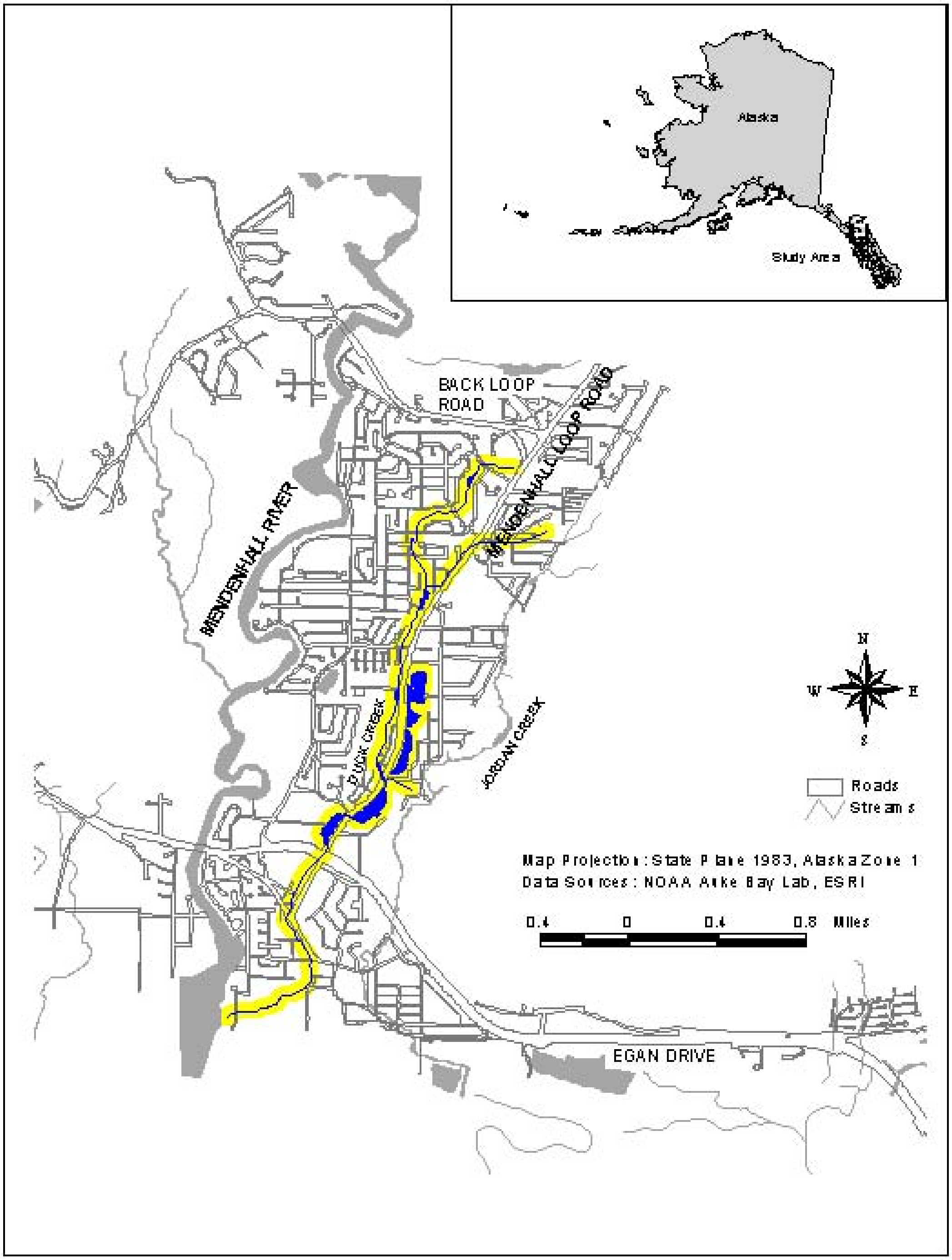

Figure 1. Location of Duck Creek

The Duck Creek Advisory Group (DCAG), which was formed to coordinate, plan, initiate, and carry out activities to restore water quality and anadromous fish habitat, has drafted the Duck Creek Watershed Management Plan (DCMP). The DCMP states that urban runoff and current land use management practices are the two key problems leading to the water quality impairment of Duck Creek (Koski and Lorenz, 1999). Designated uses for Duck Creek include (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife (Alaska Administrative Code [AAC] § 18.70.020).

Dissolved oxygen (DO) is vital to fish, shellfish and other aquatic life living in a given waterbody. These organisms respire using the oxygen dissolved in water and are essentially suffocated when there is not enough oxygen available. The DO levels observed in Duck Creek are below the minimum level required by the water quality criteria for the growth and propagation of fish, shellfish, other aquatic life, and wildlife. Low DO is frequently caused by excess nutrients, which can consume oxygen as they are chemically transformed or can cause algal blooms which then die-off and consume oxygen as they decompose. However, the nutrient observations available for Duck Creek do not indicate that these processes are contributing significantly to the DO impairment. Rather, the DO impairment is for the most part attributable to groundwater inflow, iron in the groundwater, and in-stream alterations. Groundwater is typically lower in DO than surface waters. As a result, when the groundwater flows into a stream, a depression in DO is usually observed near the location of the inflow. As the water flows downstream from a groundwater inflow, it is aerated and the DO level increases.

In the Mendenhall Valley, the contribution of low DO from groundwater is compounded by the high dissolved iron content of the groundwater. Much of the valley is underlain by glaciomarine deposits that are high in iron. As the groundwater flows through these deposits, it picks up iron which ends up in surface waters. When this dissolved iron is exposed to the air, it is oxidized, consuming oxygen and forming iron floc. This iron floc can blanket the bottom of the stream, smothering and displacing the natural aquatic community. The inflow of low DO and iron-rich groundwater has been substantially increased by the channel modifications that have taken place in Duck Creek. The stream channel has been modified extensively over time by channel relocation, gravel mining, streambank encroachment, and road crossings. Several large borrow pits and dredge ponds characterize the East Fork. The creek typically has an orange color at several locations caused by mats of iron floc on the streambed and stream surface. Channel and streamflow alterations also contributed to habitat impairment in Duck Creek. Combined with highly permeable reaches of streambed, these alterations have led to significantly reduced flow, and in some cases to the complete absence of flow, during the critical salmon smolt migration. Because the iron and DO impairments in Duck Creek are related, this TMDL addresses these two impairments together, establishing an iron loading capacity for both the iron TMDL and the DO TMDL.

Land Use

Thirty-six percent of the 1,080-acre Duck Creek watershed is covered by impervious surfaces such as roofs, roads, and parking lots (Lorenz, 1998). The remainder is a mix of cultivated landscaping, nonvegetated athletic fields, natural vegetation, and wetlands. Nearly half of the watershed provides space for residential housing, yards, and driveways. Most of the housing is single-family construction. Another third of the watershed is used for transportation or commercial interests. Based on this land use distribution, the Duck Creek watershed was divided into the following land use categories and areas: residential (540 acres), transportation and utilities (83 acres), commercial (282 acres), and recreation and wetland (175 acres.) Table 1 summarizes the land use distribution.

Table 1. Land use distribution in the Duck Creek watershed

Land Use	**Area (acres)**[a]
Residential	540
Transportation	83
Commercial	282
Recreation/Wetland	175
Total	**1,080**

[a] Estimated from land uses and information presented in Lorenz, 1998.

Climate

Historical climate data are available from the Juneau International Airport (Station 504100), adjacent to the lower reach of Duck Creek. The temperature ranges from a normal daily minimum temperature of 19 °F (-7.2 °C) in January and 48 °F (8.9 °C) in July to a normal daily maximum temperature of 29 °F (-1.7 °C) in January and 64 °F (18 °C) in July. Rainfall averages 54 inches per year, ranging from less than 3 inches per month to well over 7 inches per month. Snowfall averages 99 inches per year, ranging from 0 to 26 inches per month. Wind averages about 8 mph daily (NOAA National Climate Data Center).

Applicable Water Quality Standards

TMDLs are developed to meet applicable water quality standards. These standards may include numeric water quality standards, narrative standards, and other associated indicators of support of beneficial uses. The numeric target identifies the specific goals or endpoints for the TMDL that equate to attainment of the water quality standard. The numeric target may be equivalent to a numeric water quality standard where one exists, or it may represent a quantitative interpretation of a narrative standard. This section reviews the applicable water quality standards and identifies an appropriate numeric indicator and an associated numeric target level for the calculation of the TMDL to address low DO and iron impairments in Duck Creek.

Designated Uses

Designated uses for Alaska's waters are established by regulation and are specified in the State of Alaska Water Quality Standards (18 AAC 70). For fresh waters of the state, these designated uses include (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife. Duck Creek only partially supports these designated uses.

Parameters of Concern

The Alaska 1998 § 303(d) list of impaired waters identified Duck Creek as water quality-limited because of dissolved gas, debris, metals, fecal coliform bacteria, and turbidity. The dissolved gas impairment refers to occurrences of dissolved oxygen concentrations below water quality standards. The metals impairment refers to elevated levels of iron from groundwater entering the creek. This TMDL addresses only the dissolved oxygen and iron impairments to the creek.

Applicable Water Quality Criteria and Numeric Target

Duck Creek is impaired due to elevated iron and depleted DO. This section describes the associated water quality criteria for each parameter. Because the iron and DO impairments are related, the TMDLs establish an iron loading capacity that is expected to result in attainment of water quality standards for both iron and DO.

Dissolved Oxygen

The most stringent of Alaska's water quality standards with respect to dissolved oxygen (DO) is for the growth and propagation of fish, shellfish, other aquatic life and wildlife. The applicable standard states that:

> *D.O. must be greater than 7 mg/L in waters used by anadromous and resident fish. In no case may D.O. be less than 5 mg/L to a depth of 20 cm in the interstitial waters of gravel used by anadromous or resident fish for spawning. For waters not used by anadromous or resident fish, D.O. must be greater than or equal to 5 mg/L. In no case may D.O. be greater than 17 mg/L. The concentration of D.O. may not exceed 110% of saturation at any point of sample collection. (18 AAC 70 (1)(C))*

The water column DO criterion and the DO TMDL numeric target in Duck Creek, which has historically supported salmon runs, is therefore 7 mg/L. DO values as low as 0.61 mg/L have been observed in the creek.

Iron

Duck Creek is also listed for dissolved iron. The iron and DO impairments in Duck Creek are thought to be related because dissolved iron is a source of oxygen demand. In fact in Duck Creek, dissolved iron is thought to be one of the dominant sources of oxygen demand, and that attainment of water quality standards for iron will translate into dissolved oxygen standard attainment. The iron criterion in Alaska's water quality standards and the iron TMDL numeric target is the EPA Drinking Water Standard of 0.3 mg/L (EPA, 1996).

Critical Conditions

The criterion of concern for DO in Duck Creek is related to the growth and propagation of fish, shellfish, other aquatic life, and wildlife. Many species are potentially affected by low DO, and an indicator species is frequently selected to facilitate the assessment of overall habitat quality for fish and wildlife. Coho salmon have been selected as an indicator species in Duck Creek, where the coho run has declined from about 500 in the 1960s to less than 20 in 1998 (Koski and Lorenz, 1999). Coho are highly migratory at each stage of their life history and are dependent on good habitat conditions in their migration corridors (e.g., lack of physical obstruction; adequate water depth, water velocity, water quality, and cover.) Small streams such as Duck Creek (total drainage area of 1,080 acres) are particularly important to coho salmon, providing nearly 90 percent of their spawning and rearing habitat. In Alaska, nearly all coho are wild fish that spend about 2 years in fresh water followed by about 16 months at sea before returning to reproduce in natal streams (Lorenz, 1998).

Coho salmon enter spawning streams from July to November, usually during periods of high runoff (Lorenz, 1998). Once the salmon have migrated to their natal stream, the female digs a nest, called a redd, and deposits eggs that the male fertilizes with sperm. The eggs develop during the winter and hatch in early spring; the larvae, called alevins, remain in the gravel utilizing the egg yolk until they emerge as fry in May or June. During the fall, juvenile coho can travel miles before locating off-channel habitat, where they pass the winter free of floods. After one or two rearing years, juvenile coho migrate to the sea as smolt in the spring. Time at sea varies, with some males (called jacks) maturing and returning after only 6 months at sea at a length of about 12 inches, while most fish stay 18 months before returning as full-size adults.

The entire freshwater portion of the coho salmon life cycle takes place in Duck Creek, including spawning, egg development and one to two rearing years. As a result, the DO impairment to the creek has the potential to affect many salmon lifestages throughout the year, from adults migrating upstream to spawn, to eggs and alevins developing in the stream gravel, and juveniles during their rearing years. This effect is likely to be even more pronounced during periods of low flow, which commonly occur from January through July. Adult salmon returning to breed encounter pools with low DO and could experience physiological stress and fail to successfully reach the breeding grounds. This physiological stress might also impact the quality of the eggs produced once breeding begins. Insufficient oxygen in the water column, combined with siltation of the stream bottom by sediment (which was addressed in the Turbidity TMDL) and iron floc, reduces the DO content of the interstitial waters of gravel used for spawning, potentially leading to higher alevin mortality and the emergence of weaker fry. The emergent fry would already be stressed and subject to higher mortality as they encounter low DO during their migration to sea.

According to Lorenz (1998), egg-to-fry survival of coho salmon in the creek is close to zero as a result of sedimentation and low DO levels, and nearly all coho rearing in Duck Creek migrated there from outside the watershed.

Water Quality Analysis

Water Quality Data

The data available for assessing the condition of Duck Creek with respect to DO and iron are described in this section. In general, a good amount of data is available for flow, precipitation, DO, temperature, pH, and conductivity. Data on iron and other potential sources of oxygen demand such as 5-day biochemical oxygen demand (BOD_5) and nutrients are extremely limited. In some cases the quality of the data has been questioned by the responsible agency or the temporal coverage of the data is not adequate for certain analyses. However, TMDL guidance (USEPA, 1991) provides that TMDLs should be developed using the best available information, especially when nonpoint sources are the primary concern. Therefore, as part of the Duck Creek watershed characterization process, all data available to support the DO and iron TMDLs were reviewed and are summarized in this section.

1994-1998 U.S. Geological Survey Streamflow Monitoring

Daily streamflow has been measured since December 1993 at a United States Geological Survey (USGS) gaging station (15053200) located downstream of Nancy Street in the Duck Creek watershed (Figure 2). The DCMP (Lorenz, 1998) indicates that flow at the gaging station represents discharges from approximately 75 percent of the watershed (approximately 810 acres). It is estimated that approximately 46 percent of the total precipitation that falls in the Duck Creek watershed is transported into the stream through overland runoff (Lorenz, 1998). The remaining 54 percent is believed to enter Duck Creek as groundwater or through sewer systems. Because flow in Duck Creek is heavily influenced by groundwater, there is a substantial lag between precipitation events and peak flow stages. Duck Creek has been observed to peak approximately 24 hours after the neighboring Jordan Creek. Annual and monthly average flows and precipitation for 1994 to 1998 are presented in Appendix B, Table B-1.

Peak monthly discharges and precipitation in the watershed occur on average during the months of September and October. This represents the period of maximum runoff and increased nonpoint source pollutant loading from areas in the Duck Creek watershed. Periods of low flow which occur from January through July are also critical to water quality in Duck Creek because this is when the impact of groundwater inflow is at its peak. Groundwater inflow remains relatively constant over the course of the year, but it makes up a larger percentage of total streamflow at lower flows when the contributions from precipitation and runoff are at their lowest. As a result, groundwater conditions can dominate in-stream water quality when groundwater is the main contributor to streamflow.

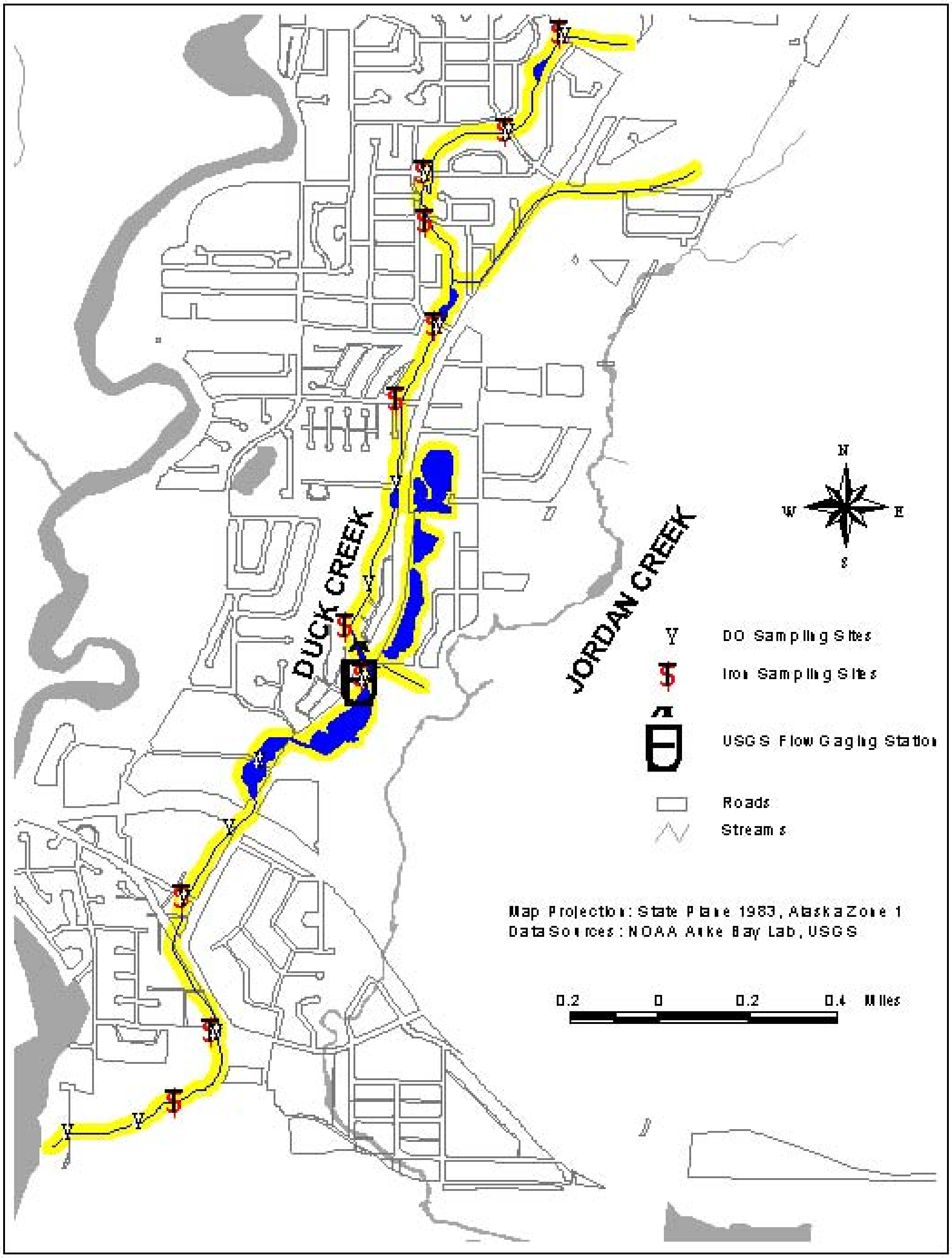

Figure 2. DO, iron and streamflow sampling locations in Duck Creek

1997 USDA Forest Service Iron Sampling

In the United States Department of Agriculture Forest Service's *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998), the stream reaches with the heaviest inflow of groundwater with high concentrations of dissolved iron were found to be those areas where the channel or ponds had been mechanically deepened into the underlying floodplain and glaciomarine deposits (Beilharz, 1998). The stream is underlain by three types of material: alluvial outwash composed mainly of gravel, floodplain deposits of silt and organic soils, and glaciomarine sediments composed of gravel, sand, silt, and dense clay. Natural and human stream channel realignment has resulted in sections of the stream bottom intercepting each of these layers. The majority of the streambed consists of floodplain deposits of silt and organic soils. Where alluvial outwash is the predominant streambed material, the stream experiences significant flow losses, especially in the vicinity of Del Rae Street. Where the stream channel intersects the glaciomarine sediments, the groundwater has high iron concentrations. The iron in groundwater is in a reduced state and oxidizes when it flows into the stream and comes into contact with higher DO levels, forming iron floc. A single groundwater seepage observation was collected at each of 11 sites in June 1997. This set of observations showed total iron concentrations as high as 10 mg/L (the data are presented in Appendix B, Table B-2).

The 1997 USDA Forest Service iron sampling data were used to identify three distinct locations where iron-rich groundwater is seeping into the stream. These locations are Taku Boulevard, below Berners Avenue, and the dredge ponds on the East Fork.

1996 U.S. Geological Survey Water Quality Monitoring

A limited amount of water quality data was available from the USGS, with one sample collected at each of four sites (Appendix B, Table B-3). The collection sites are in close proximity to the locations of high iron groundwater inflow. The observed nutrient concentrations from the USGS data shown in Table B-3 are all low (NO_2 < 0.01 mg/L, NO_x < 0.23 mg/L, NH_3 < 0.285 mg/L and TKN < 0.37 mg/L), suggesting that nutrients are not a significant source of oxygen demand in Duck Creek. Therefore it appears that the high iron concentrations at these locations represent the majority of the in-stream oxygen demand. The observed DO concentrations are consistent with the DO trends from sampling done by the National Marine Fisheries Service (as described below). These observations, along with the Alaska Department of Environmental Conservation (ADEC) water quality monitoring data presented below, were used to support the assumption that nutrients are not contributing significantly to the DO impairment to Duck Creek.

1994-1995 Alaska Department of Environmental Conservation Water Quality Monitoring

ADEC collected water quality samples on three dates. These samples were tested for various organic chemicals, nitrate, nitrite, BOD_5, and chemical oxygen demand (COD). Samples were collected at five sites: Taku Boulevard, Airport Boulevard, Dredge Lake, Stump Pond, and Rainbow Road. Dredge Lake is above Taku Boulevard and may serve as a headwater for Duck Creek. Based on street maps and various names for the station, Rainbow Road may be Rainbow Row, which drains into the East Fork. The exact location of Stump Pond is not known, but it is suspected to be on the East Fork. The data collected by ADEC are spatially scattered to such an extent that only a general pattern of water quality can be determined and are presented in Appendix B, Table B-4. The low nutrient and BOD values observed (on average, NO_2 = 0.3 mg/L, NO_3 = 0.3 mg/L, BOD_5 = 2.2 mg/L and COD = 16 mg/L) support the assumption that nutrients are not contributing significantly to the DO impairment to Duck Creek.

1999 Groundwater Monitoring

Groundwater inflow typically has low levels of pollutants and reflects background or unimpacted conditions. Several groundwater wells have been placed in the Duck Creek watershed. In an unpublished report by Dr. Randy Stahl at the University of Alaska Southeast, monitoring results from three of these wells were summarized (Stahl, 1999). The three wells were sampled in April, May and June of 1999, and the results for total iron and DO are presented in Appendix B, Table B-5. Well 3, located near Cessna Drive, was impacted by construction during the study, and sampling was moved to Well 4, which is located south of Berners Avenue. Both wells 3 and 4 are located near the stream and were observed to go dry when the stream went dry, suggesting that they were influenced by in-stream conditions and may not be a good reflection of groundwater conditions. Well 17 is located at El Camino Street and is near a pool and the East Fork. The three iron readings for Well 17 are 8 mg/L or higher. In Beilharz (1998), high iron readings were linked to discharge from the glaciomarine sediments, which suggests that Well 17 might be located in such sediments and therefore representative of typical iron seepage conditions where these sediments are intercepted. For an unmodified channel, however, these sediments would not be directly intercepted, and background iron seepage to the creek would likely be substantially lower.

1992-1993 Alaska Water Watch Water Quality Monitoring

During 1992 and 1993, local students from Juneau Youth Services, Miller House, collected water quality samples at nine sites in Duck Creek as part of the Alaska Water Watch (AWW) program. The geographic locations of the stations in Duck Creek are referenced by street names and are presented in Figure 2. Parameters measured include water temperature, DO, pH, turbidity, specific conductivity, alkalinity, and fecal coliform bacteria. The in-stream data collected at these sites did not have any corresponding flow, and the period of record did not overlap with the flow data collected at the Nancy Street USGS gaging station. The DO data available for 18 sampling events between 1992 and 1993 were combined with a subset of the NMFS data (described below) for use in the TMDL analysis and model development. These data are included in the data analysis summarized in Table B-6 in Appendix B.

1994-1997 National Marine Fisheries Service Sampling

The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) has conducted both continuous and periodic water quality sampling of Duck Creek using portable Hydrolab electronic sensors. Measurements were taken of temperature, pH, specific conductivity, salinity, DO, redox, and water level. These data have temporal overlap with the USGS flow record and constitute the bulk of the available DO data. Data were collected at

25 sites along the main stem and 5 sites on the East Fork. Data were available for 47 sampling events between 1994 and 1997.

Because many stations were not sampled on a regular basis, long-term DO trends could be determined for only 13 sites along the main stem of Duck Creek, and only those stations with long term records were used in developing the TMDL. Table B-6 in Appendix B summarizes the AWW and NMFS DO data at the 13 sites used to develop this TMDL.

Analysis of Iron, DO, Temperature, and pH Data

The available in-stream measurements were combined by parameter and station to evaluate trends and possible exceedances of the water quality standards. The data that overlap the flow record were also used in determining relationships with flow. Not all stations were sampled on each sampling date, with the number of observations varying between 14 and 61 readings per station from 1992 to 1997. The location and distance upstream from the mouth for each station was estimated with the best available maps and data. Some stations had several names, and all distances were rounded to the nearest 5 feet. (Appendix A contains the list of DO stations from all the studies.)

Iron

No analysis of iron data is presented in this report. The available iron data are limited to the data presented in Beilharz (1998), which was summarized in the previous section. It was necessary to assume these readings represent the total iron concentrations in the stream. This assumption is likely to result in higher predicted concentrations in the stream, which represents a conservative assumption and contributes to the implicit margin of safety for the TMDL.

Dissolved Oxygen

Dissolved oxygen readings were available at 13 stations between 1994 and 1997, with the number of observations at individual stations varying between 19 and 63. Many stations were not sampled on a regular basis. Long-term statistics were determined for 13 sites along the main stem of Duck Creek (Table B-6). Figure 3 shows a summary of the mean DO and iron concentrations for 1997. As shown in the figure, the average DO is relatively low near Taku Boulevard (just above 7 mg/L) and is higher downstream (nearly 10 mg/L) until Nancy Street, where the East Fork joins the main stem and DO drops to 6.5 mg/L. The DO increases again below Nancy Street (between 8 and 9 mg/L) until the vicinity of Berners Avenue, where it again drops below 8 mg/L. From below Berners Avenue to the mouth of the stream, DO increases again, reaching 12 mg/L near the mouth. The iron concentrations from June 1997, also plotted in Figure 3, show a co-occurrence of increased iron concentrations with decreased DO concentrations.

Figure 4 shows the maximum, minimum, and mean DO concentrations for all sample dates (1992 to 1997). The same DO concentration trend is observed for 1992 to 1997 as for 1997 alone, with depressions in DO at Taku Boulevard, Nancy Street, and Berners Avenue.

Moving downstream, DO readings at adjacent stations were compared to evaluate the correlation of immediate upstream and downstream conditions. Figures 5a and 5b present pairwise comparisons of DO at adjacent stations. In all but two cases, there appears to be a strong correlation between the DO at each station and the DO at the station immediately upstream, suggesting that conditions immediately upstream are the major determinant of downstream conditions. Where a tributary enters the stream (Nancy Street) or there is groundwater seepage from the glaciomarine sediments (Berners Avenue), the correlation is not as pronounced, which is to be expected as a new flow source with different water quality is added at those points.

As part of the analysis, the DO readings were compared to the criterion of 7 mg/L. Table B-6 summarizes the data for the 13 stations used, including the number and percent of samples that do not meet the criterion. This exceedance analysis shows the same pattern of DO depression and improvement from Taku Boulevard to Nancy Street, from Nancy Street to Berners Avenue, and from Berners Avenue to the mouth of the creek. In each case, as shown in Figures 3 and 4, the DO depression coincides with an elevated iron concentration from groundwater inflow.

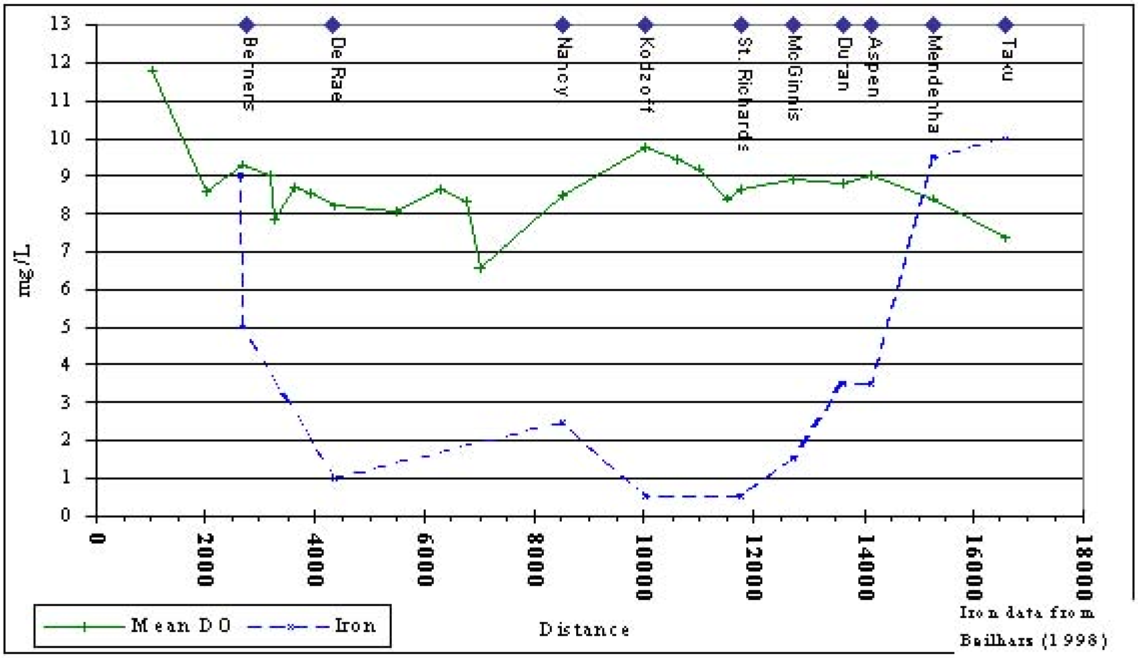

Figure 3. 1997 DO and iron monitoring data in Duck Creek

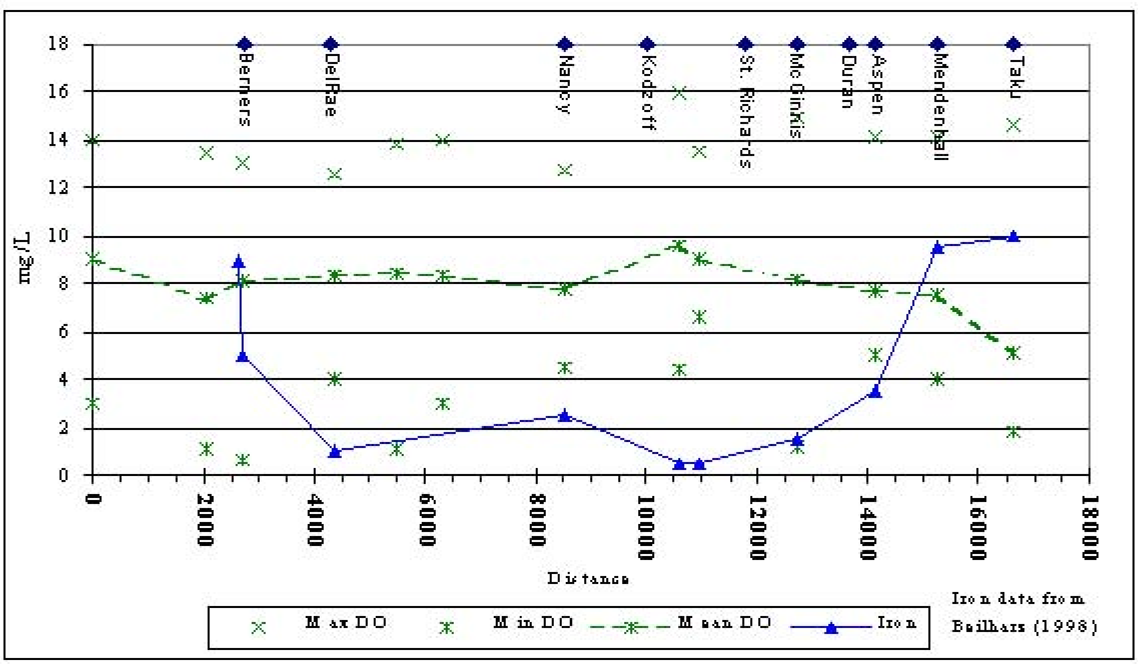

Figure 4. Summary of 1992-1997 DO and 1997 iron monitoring data in Duck Creek

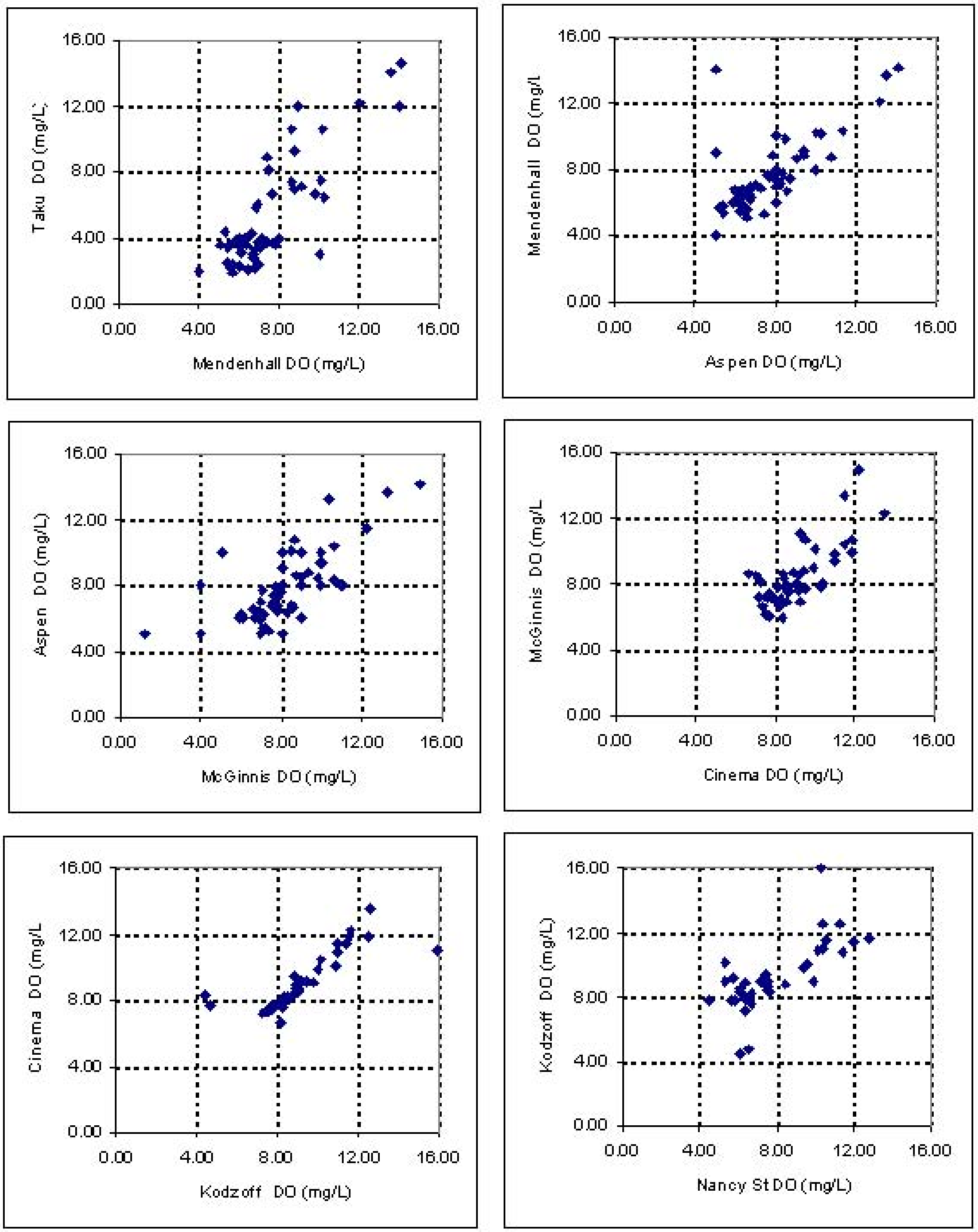

Figure 5.a. Pairwise comparison of DO at adjacent monitoring stations

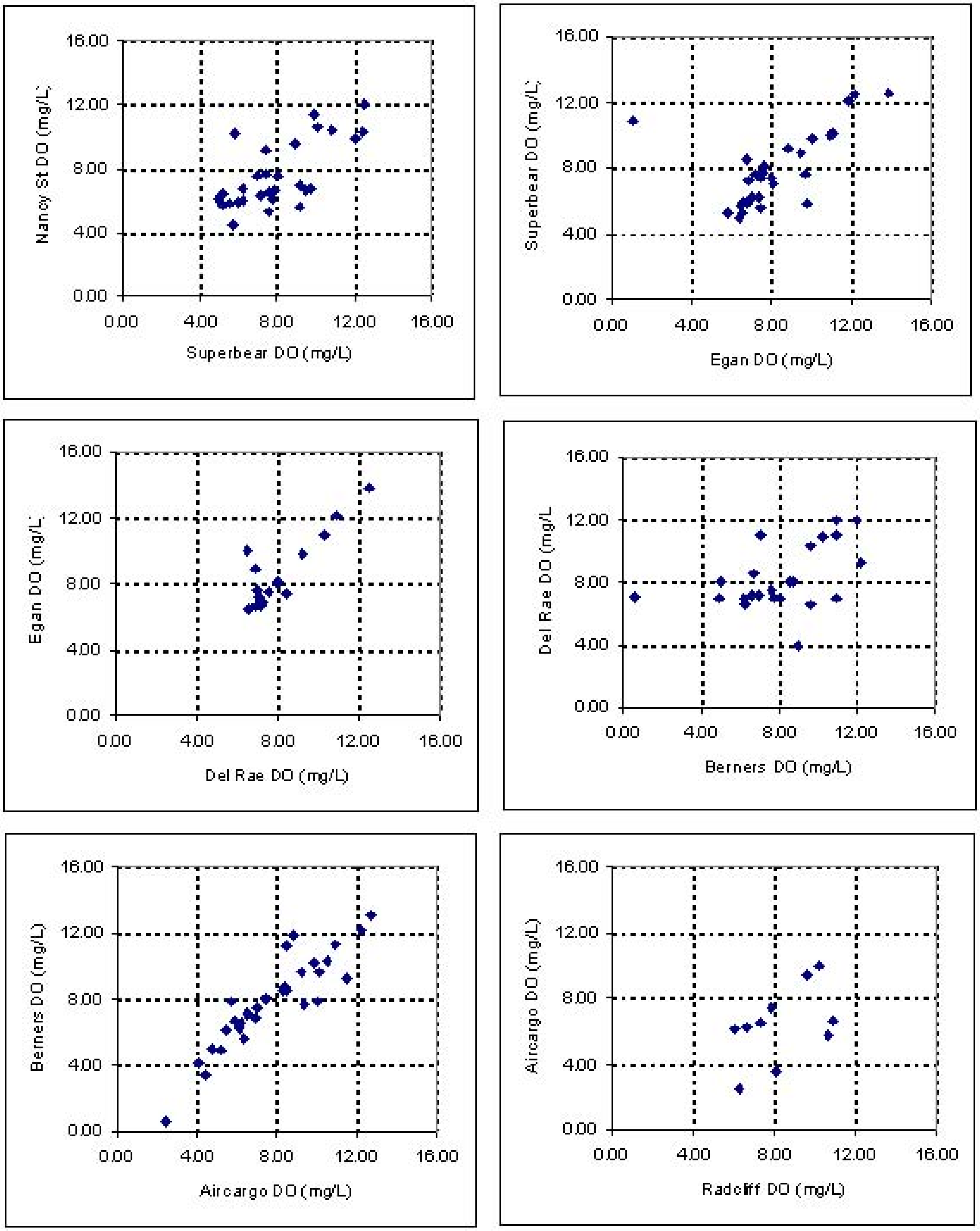

Figure 5.b. Pairwise comparison of DO at adjacent monitoring stations *(continued)*

Temperature

Because DO saturation is dependent on temperature, temperature and DO data were evaluated together for Duck Creek. In general, low DO concentrations occur at lower flows and higher water temperatures. The saturated DO concentration increases with decreasing temperature, and multiple-year plots of DO versus temperature should show this relationship. The monitoring data were analyzed to see if the DO-temperature relationship in Duck Creek followed these trends. Figures 6 and 7 show the correlation of temperature with month and with flow. These figures show that there is very little correlation between streamflow and in-stream temperature, but that the overall seasonal patterns of temperature do hold, with maximum water temperatures occurring in June through August and minimum temperatures occurring in January and February. For the period between 1992 and 1997, the maximum temperatures varied between 10 °C at Taku Boulevard and 22.3 °C at McGinnis Street. Although minimum temperatures ranged between 0 °C and -1 °C, the DO in Duck Creek is generally below 80 percent of saturation.

pH

When the pH significantly differs over the length of a stream, a greater portion of the oxygen deficit might be due to chemical speciation and equilibrium processes and not the decay and reaeration processes. When the pH does not significantly differ, stream chemistry remains relatively constant, and comparisons between stations are simplified. This condition was assumed in developing the simplified model for Duck Creek. On 58 dates, pH readings were taken from as few as 3 stations and as many as 27 stations. On 19 of these dates, the difference between the minimum and maximum pH in the creek exceeded 1 pH unit. When the pH values for each month were compared, a pattern similar to that of the temperature analysis was seen, with the maximum pH readings generally occurring from June to August. The sample dates used for the model did not have pH variations above 1 pH unit.

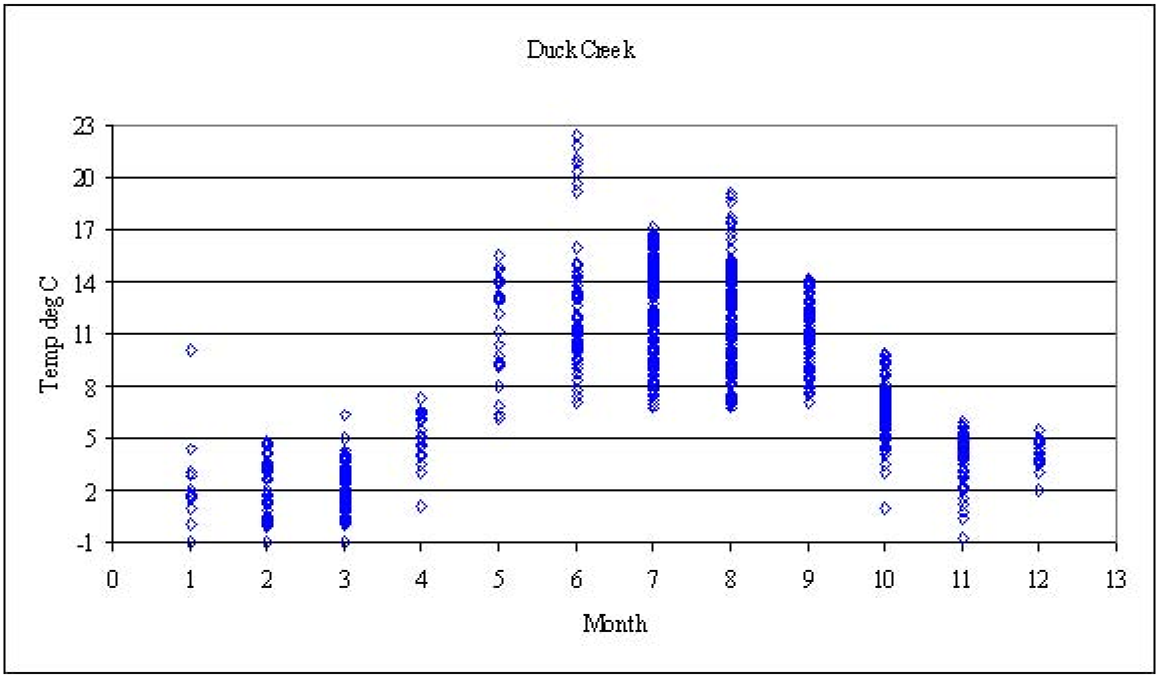

Figure 6. Temperature observations by month in Duck Creek

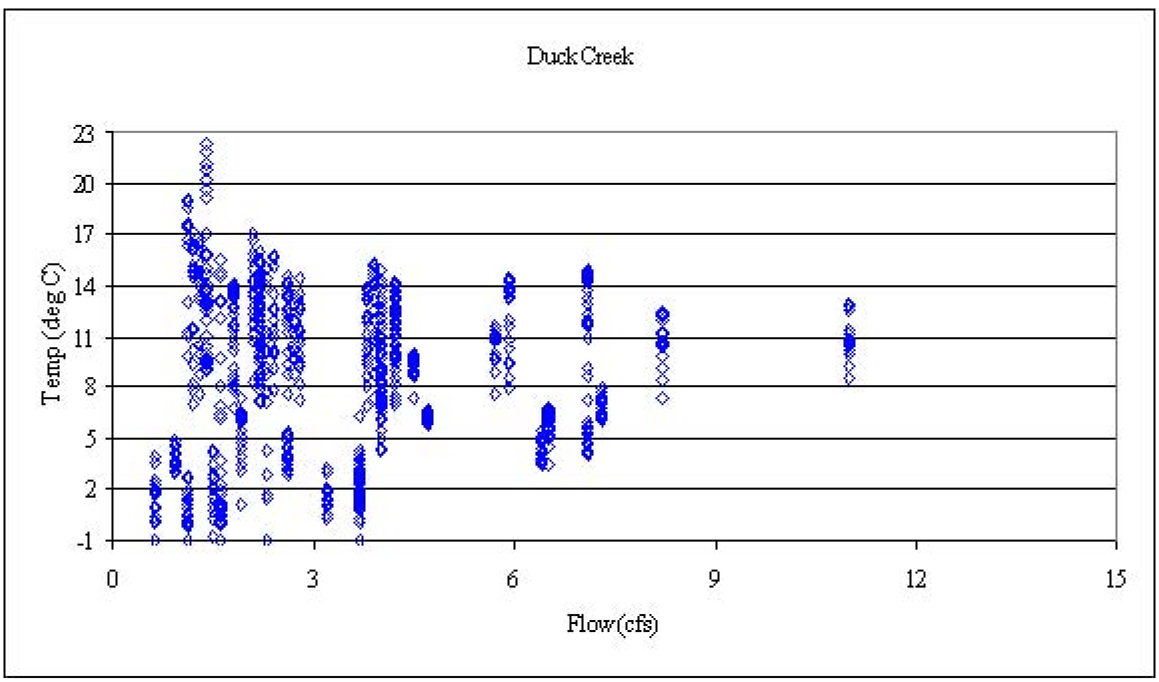

Figure 7. Temperature versus flow in Duck Creek

Pollutant Sources

An assessment of potential sources of oxygen demand is needed to evaluate the type, magnitude, timing, and location of the oxygen demand loading to Duck Creek. The source assessment includes identification of the various types of sources (e.g., point, nonpoint, background), determination of the relative location and magnitude of loads from the sources, and the transport mechanisms. Of particular concern is what loading processes cause the impairment. Pollutant sources and their loadings are often evaluated using a variety of tools, including existing monitoring information, aerial photography analysis, simple calculations, spreadsheet analysis using empirical methods, and a range of computer models.

Point Sources

No point sources are specified in the DCAG reports (Lorenz, 1998; Koski and Lorenz, 1999). A search of EPA's Permit Compliance System identified no point sources in the Duck Creek watershed. NPDES permits are required for storm water discharges in cities of 100,000 or more. Because Juneau is smaller than this, no storm water permit is required, and storm water is addressed as a nonpoint source of pollution in this TMDL.

Nonpoint and Natural Sources

Organic Material

The decay of organic material and the conversion of ammonia to nitrite and nitrate (nitrogen compounds) consume oxygen resulting in decreased DO. Possible nonpoint sources of nitrogen compounds include waste deposition throughout the watershed by wildlife and pets, leaves or other organic material deposited in the stream, and storm water runoff. Limited in-stream data are available for nitrogen concentrations and BOD_5 (see Tables B-3 and B-4). The available samples did not exceed 0.3 mg/L for ammonia, and 3.1 mg/L for BOD_5. These observed concentrations suggest that nutrients do not present a significant source of oxygen demand in Duck Creek. Assuming typical decay rates (USEPA, 1985), no reaeration, and the same velocity and distance as were used in the simplified model used to develop this TMDL, the oxygen demand for the BOD_5 and ammonia at Taku Boulevard is estimated to be 0.5 mg/L. The modeled oxygen demand for 10 mg/L of iron is about 2.5 mg/L, and the low groundwater DO creates a 6.5 mg/L oxygen demand. Each of these sources is an order of magnitude larger than the estimated oxygen demand of decaying organic material. Therefore, organic decay and nutrient conversion are not considered important sources of oxygen demand in Duck Creek.

Organic chemicals like ethylene glycol and propylene glycol can also deplete DO. These chemicals are deicing agents found in automotive antifreeze and have a high chemical oxygen demand (COD). They are delivered to surface waters primarily though runoff from urban areas. Limited in-stream data are available for COD in Duck Creek (see Table B-4). Samples collected in October 1994 ranged from 8 mg/L to 23 mg/L COD, while the February 1995 samples ranged from 5 mg/L to 45 mg/L. Samples collected in May 1995 measured COD values from 9 mg/L to

12 mg/L, suggesting that the February sample might have been an isolated event, perhaps associated with deicing activities. Because the laboratory COD measurement uses strong oxidative reagents, it is likely to reflect a much stronger oxygen demand than would occur in-stream. The relationship between laboratory and in-stream COD is not well documented in the literature. In addition, the primary means of transport of organic chemicals to the stream is through storm water runoff, which tends to be highly oxygenated. As a result, the impact of the COD values presented in Table B-4 on DO was assumed to be even lower than the 0.5 mg/L impact estimated for nitrogenous and BOD decay.

The estimates of DO demand exerted by BOD, COD and ammonia presented above support the assumption that iron-rich groundwater is the primary source causing depleted DO. It should be possible to attain water quality standards in Duck Creek by controlling the inflow of iron-rich and oxygen-poor groundwater. The additional potential sources of oxygen demand discussed above (e.g., organic decay) are not considered significant sources and are not the focus of the Duck Creek DO TMDL.

Iron

Iron concentrations vary along the length of Duck Creek and approach 10 mg/L at several locations, based on the groundwater seepage data presented in Beilharz (1998). Elevated iron concentrations can form iron floc and affect streambed aeration, which in turn affects aquatic life in Duck Creek. As the iron oxidizes, an iron floc forms and settles on the stream bottom, filling interstitial spaces in the gravel. The floc limits the aeration of the interstitial water and traps organic sediments that require DO to decompose. This decomposition can create an oxygen demand and cause low interstitial DO where the in-stream iron concentrations and associated floc formation are highest. Because no data are available on interstitial DO levels in Duck Creek, this TMDL addresses only the water column DO impairment. However, it is anticipated that reducing iron and increasing water column DO will also improve interstitial DO.

Iron can also deplete DO in the water column. Iron enters Duck Creek through groundwater from iron rich sediments that have been exposed at several locations along the creek. The iron is picked up by the groundwater as it travels through the glaciomarine sediments underlying portions of the Duck Creek watershed (Stahl, 1999). The iron in these marine sediments commonly is present as pyrite (FeS_2) in the +2 oxidation state (Stahl, 1999). The locations where groundwater high in iron discharges into the creek are distinguished by orange staining of the water and streambed and by the formation of iron floc (Koski and Lorenz, 1999, Stahl, 1999, Lorenz, 1998).

Iron in marine sediments is primarily found in the reduced (ferrous) form because of the low levels of oxygen (Stahl, 1999). This soluble iron is environmentally important because it can easily move through the groundwater and be discharged to surface waters. When exposed to oxygen, the iron is oxidized to the +3 oxidation state (ferric iron) and forms insoluble ferric oxides or hydroxides (Viswanathan and Boettcher, 1991), which precipitate out of the water column as iron floc (Lorenz, 1998). As the floc settles out of the water column, it builds up on the stream substrate, causing a red staining effect (Lorenz, 1998).

High concentrations of iron in groundwater are often associated with low groundwater DO because the DO has been consumed by iron oxidation below ground, with no opportunity for reaeration. As a result, the very groundwater that delivers increased iron concentrations to the creek also delivers decreased DO concentrations, which contributes to the instream depletion of DO seen at these sites.

The sources, fate, and transport of iron in Duck Creek are important to the DO TMDL because the formation of iron floc consumes oxygen and is considered the primary cause of low DO in Duck Creek.

The available iron data provide a general overview of the spatial pattern of iron seepage along the length of Duck Creek (Table B-2). Increased iron concentrations in groundwater seepage are seen at Taku Boulevard, Nancy Street (below the confluence of the East Fork), and below Berners Avenue. All three are believed to be locations where iron-rich groundwater is seeping into the stream (Beilharz, 1998). The flows and in-stream DO values corresponding to these iron concentrations were not available. At some locations in the creek (below Nancy Street), the water has appeared orange due to suspended iron floc (Beilharz, 1998). The three stream reaches with the highest concentrations of dissolved iron in the groundwater inflow coincide with locations where there have been modifications to the channel or excavations of ponds. These excavations often exposed the underlying sediments and glaciomarine deposits.

A more complete characterization of the distribution of iron concentrations would involve additional seepage sampling above Nancy Street on both the main stem and East Fork, and at least one site downstream of Berners Avenue, preferably at Air Cargo. Simultaneous sampling of seepage and instream iron and DO concentrations at various dates and flows would help clarify the spatial pattern and would provide some insight into any temporal patterns that might exist. Using the best available data, this TMDL identifies the locations where elevated iron concentrations have been observed in groundwater seepage (Taku Boulevard, East Fork and Berners Avenue) and explores management options to reduce their impacts. This assumes that iron floc and floc transport will be affected to a similar extent as dissolved iron.

Analytical Approach

Development of TMDLs requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. In identifying the technical approach for development of the DO and iron TMDLs for Duck Creek, the following core set of principles was identified and applied:

- The TMDLs must be based on scientific analysis and reasonable and acceptable assumptions. All major assumptions have been made based on available data and in consultation with local ADEC staff.
- The TMDLs must use the best available data. All available data in the watershed were reviewed and were used in the analysis when possible or appropriate.
- Watershed-scale models should be applied only where appropriate and when sufficient data are available. A simplified modeling approach based on empirical relationships was used for the estimation of the iron and DO concentrations in Duck Creek. Available data and the complex chemistry of iron oxidation did not support the use of watershed or water quality models.
- Methods should be clear and as simple as possible to facilitate explanation to stakeholders. All methods and major assumptions used in the analysis are described, with additional detail provided in the appendices. The TMDL document has been presented in a format accessible by a wide range of audiences, including the public and interested stakeholders.

The analytical approach used to estimate the loading capacity, existing loads, and load allocations presented below relies on the above principles and provides a TMDL calculation that uses the best available information to represent watershed and in-stream processes.

Simplified Model Development

The data available on nutrients, BOD and COD (Tables B-3 and B-4), and the negative correlation of iron and DO concentrations (Figure 3) suggest that the dominant oxygen-consuming process in Duck Creek is iron oxidation. To account for these unique dynamics contributing to impairments in Duck Creek, the TMDL analysis focused on iron concentration as a predictor of in-stream DO and a site-specific simplified model was developed to simulate flow, DO and iron interactions. The Duck Creek watershed is represented in the model by a series of eight segments. The model contains calibrated boundary conditions that set the initial DO and iron concentrations, and equations from Chapra (1997) are then used to simulate iron and DO interactions and dynamics within the stream segments. The model predicts the resulting iron and DO concentrations at the output of each segment. Those output concentrations are then used as input to the next downstream segment. Areas of expected or known groundwater inputs are also included within the model and are represented by input flows and concentrations within the appropriate segments. The model was developed using flow and iron information found in Beilharz (1998) and DO monitoring data. Details on the estimation of flow and simulation of iron and DO within the model are contained in Appendices C and D, respectively. The following sections provide general summaries of the modeled estimation of flow and iron and DO concentrations, the calibration of the model, and the assumptions and limitations associated with the model.

Estimation of Flow

Equations used in the model to simulate DO and iron dynamics are dependent on stream flow. Therefore, to simulate the instream conditions of Duck Creek, it was necessary to have input flows for each simulation time period and modeled segment. The flow pattern in Duck Creek is complex and varies along the length of the stream, but continuous flow observations are available only at Nancy Street. A method was developed to estimate flows at locations of interest along Duck Creek using information on flow regimes and percentages from the *Duck Creek Hydrology Baseline Conditions* report (Beilharz, 1998). The flow estimation method, presented in detail in Appendix C, was used to estimate the flow at three of the eight stream segments simulated: Taku Boulevard, Mendenhall Boulevard, and Stephen Richards Memorial Drive. Observed flows were used for the Nancy segment, and flows for the remaining segments, Aspen Avenue, Duran Street, McGinnis Drive, and below Kodzoff Acres, were interpolated from the estimated flows in adjacent segments.

Interaction of Iron and DO

Iron and DO losses due to oxidation and floc formation, as well as DO increases due to in-stream aeration, were calculated for each stream segment. DO concentrations change along the channel due to groundwater inflow. The groundwater, which is assigned an iron concentration in each segment based on the observed monitoring information in Table B-5, will increase or decrease the in-stream iron concentration. A constant concentration of 0.3 mg/L was used to specify the groundwater iron concentration for segments with groundwater inflows that are not influenced by glaciomarine sediments (Aspen Ave, Duran St, McGinnis Dr, Stephen Richards Memorial Dr, Kodzoff Acres and Nancy St.) An iron concentration of 10 mg/L was assumed in groundwater inflows for segments where the glaciomarine sediments have been exposed (Taku and Mendenhall Blvds). The DO concentration was estimated for each type of groundwater (high iron and low iron) based on the groundwater observation data presented in Table B-5. A constant DO concentration of 4.9 mg/L was used in the model for groundwater with an iron concentration of 0.3 mg/L. A DO concentration of 3.2 mg/L was assumed for iron-rich (10 mg/L) groundwater[1]. Since the groundwater DO in both cases is lower than the in-stream DO concentration, the low groundwater DO contributes to the depletion of in-stream DO, especially in those segments where glaciomarine sediments have been exposed. The details of the equations used to calculate iron and DO in each stream segment are presented in Appendix D.

Estimation of Hydraulic Condition

The hydraulics of the stream depend on the stream cross section, slope, and bottom roughness. The hydraulics affect the decay, settling and aeration rates within the segment, affecting the model

[1] The following regression relating groundwater iron concentrations to groundwater DO concentrations was developed based on the data presented in Table B-5:

$$[DO] = -0.187*[Fe]+5.0397 \ (R^2 = 0.6315)$$

Therefore, for [Fe] = 10 mg/L, [DO] = 3.2 mg/L and for [Fe] = 0.3 mg/L, [DO] = 5.0 mg/L prediction of instream DO and iron. The slope of each model segment was estimated based on the elevation of the segment endpoints from the maps included in Beilharz (1998). A constant roughness of 0.035 was applied to the entire stream. The width of the stream was assumed to be 4 feet everywhere except for the segments of Aspen and Duran, where a width of 20 feet was used. A wider channel was used to represent these two segments because they consist of ponded water along the majority of their length, rather than free-flowing streams. The Manning's equation (Linsley et al., 1992) was used to calculate the flow velocity and depth of each stream segment. Since the depth of each model segment is unknown, the iteration method was used to estimate depth so that the flow calculated using Manning's equation matched the flow estimated for each model segment.

Model Calibration and Validation

The model was calibrated using DO data from August 1995 and validated using DO data from August 1997 (see Figures D-1 and D-2 in Appendix D). (Because iron data are available only for June 1997, iron data used in all calibrations are the June 1997 data.) To further verify the model, it was then used to simulate the instream conditions for June 15, 1997, and the mean flow for June 1997 (Figure 8), corresponding to the time period when groundwater seepage data were collected (Table B-2). Iron predictions closely matched the patterns and concentrations of the observed iron data (Figure 8). The model DO predictions for June 1997 show poor agreement with the instream DO observations, which frequently exhibited supersaturated conditions. The predictions did, however, capture the overall pattern of the June DO measurements, with DO values consistently underestimated by approximately 3 mg/L (see Figure 8). A review of the precipitation data revealed a 0.56 inch rain storm on June 12, 1997. The peak value observed at 14,000 feet could represent algal activity from nutrients washed into the stream during rains from the three days prior to the sampling date. The correlations in Figures 5a and 5b suggest that the effect of such algal activity would translate to downstream sites. This activity and the resulting supersaturated DO conditions cannot be simulated by the model. However, the model's capture of the water quality pattern and its good calibration in August 1995 and August 1997 indicates its appropriateness and successful simulation of Duck Creek iron and DO dynamics.

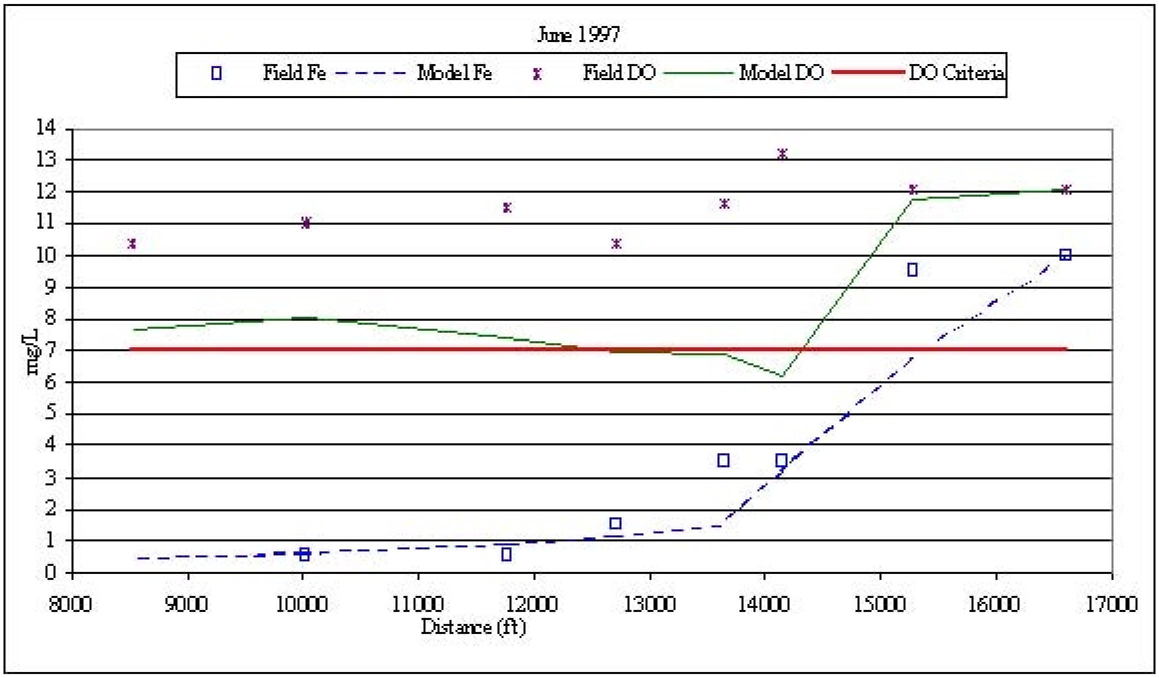

Figure 8. Validation of simplified model simulation of iron and DO for June 1997

Limitations of the Iron and Dissolved Oxygen Model

Duck Creek has a documented DO problem, which could be caused by pollutants from several sources, including urban runoff containing nitrogen and organic material, high instream iron, increased inflow of low DO groundwater, and limited instream reaeration caused by hydraulic problems. The hydraulics are complicated by the loss of water through portions of the streambed.

Model selection required consideration of the available data and a determination of which pollutants represent the largest source of oxygen demand. Comparison of the monitoring data to the DO saturation value shows instances of the stream being supersaturated with DO, suggesting algal photosynthesis. Table 2 presents the comparison for June 15, 1997. Since monitoring data also show elevated levels of iron, the ideal model would simulate iron chemistry, BOD, nitrogen, phosphorous, and algae. The realistic simulation of iron chemistry requires data for pH, temperature, cations like sulfate and nitrate, and competing metal ions. A eutrophication model, which can simulate supersaturation of DO, requires data for BOD, algae, phosphorus, and nitrogen. Due to limited data, implementation of such a model was not possible.

Table 2. Instream DO saturation values on June 15, 1997

Site	Temp (ºC)	DO (mg/L)	DO Saturation (mg/L)	DO Saturation (%)
Taku Blvd	7.11	12.10	11.76	102.9
Mendenhall Blvd	7.45	12.10	11.66	103.8
Aspen Ave	8.74	13.20	11.29	117.0
Duran St	9.23	11.60	11.15	104.0
McGinnis Dr	11.07	10.40	10.66	97.6
Stephen Richards Memorial Dr	10.37	11.50	10.84	106.1
Kodzoff Acres	11.06	11.00	10.66	103.2
Nancy St	13.08	10.40	10.17	102.3

Water Quality Data Limitations

The limited water quality and flow data available for Duck Creek are described in the Water Quality Analysis section of this report. The lack of nitrogen and phosphorus data makes it impossible to appropriately apply a eutrophication model, which limits modeled DO values to saturation levels or less. The single round of iron sampling and lack of cation concentrations makes it impossible to simulate iron chemistry in detail. The available BOD and nitrogen concentration data suggest that oxidation of these parameters would not consume more than 0.5 mg/L of DO at typical rates. Given these data limitations, the best available method for iron simulation is an exponential decay with time, represented by the simple Streeter Phelps model found in Qual2EU (Chapra, 1997). Loss of iron occurs through decay and settling, with material that settles to the bottom assumed to be lost from the system. Temperature correction of rates, DO saturation, and groundwater inflow are included in this simplified model following the methods of Qual2EU. While settling rates would ideally be corrected based on water temperature and water density changes, this approach would require particle size distributions and complicated estimates that could introduce further error into the model. Oxygen saturation is included in the model using the equation from Chapra (1997) relating the steady decline in DO saturation to instream temperature.

Hydraulic Limitations

Predictions of decaying sources are coupled to the hydraulics of the stream. The hydraulics of Duck Creek are complicated by the fact that some reaches gain flow, while others lose it. Models like Qual2EU have the ability to include withdrawals, which could be used to simulate losing reaches. However, the models assume that the loss is known for all flow conditions, which is not true for Duck Creek, where flow losses vary depending on the instream flow and the level of the groundwater table. An attempt was made to use the flows in Table C-1 to estimate upstream to downstream flow ratios, but the ratio values varied too much from low to high flows to allow a reliable simulation. An alternative approach was used to estimate the incremental inflow for each stream reach from the data in Table C-2. The estimated in-stream flows are therefore steadily increasing in the downstream direction for all flow scenarios. The error in estimating flow at each model segment greatly affects the estimate of groundwater inflow and its associated DO and iron loadings to the Creek. The collection of additional flow data at more locations along the Creek will help minimize this error.

Model Accuracy Limitations

The model equations being used have an accuracy of 0.1 mg/L, meaning that a prediction of 7 mg/L is actually between 6.9 and 7.1 mg/L. The fit of the model to monitoring data will not approach this level of accuracy. Different flow conditions will create instream conditions that can not be exactly matched. A defensible model will minimize the error between actual conditions and predicted values, with the calibration and validation runs close to or matching several observed values, and having about the same number and magnitude of overpredicted values as underpredicted values.

The ability of the model to match the monitoring data is dependent on the reaction rates used. The model had 3 reaction rates: reaeration, settling, and decay. The reaeration rate is dependent on velocity, which varies with stream channel morphology. With sufficient monitoring data, reach variable reaeration rates can be derived. Sufficient data were not available to do this in Duck Creek. Therefore, a constant reaeration rate was used in the model. For shallow streams, most equations predict reaeration rates that exceed 20/day. The typical range of observed reaeration rates for a shallow stream like Duck Creek, however, is between 2/day and 15/day (USEPA, 1985). Through calibration of model parameters, the model reaeration rate was set to 19/day.

The overall iron removal rate was calibrated first, followed by a calibration of the predicted DO. In the model used, iron is lost due to decay and settling, while DO is impacted only by decay. Since decay is involved in both the iron and DO equations, the impact of low DO on the decay rate should be taken into consideration. Available literature on the impact of low DO on decay rates deals with the decay of nitrates, and the impact is not significant for DO levels above 3 mg/L. The model predicted DO less than 3 mg/L for the stream reach between Taku and Mendenhall Boulevards. Accounting for the effect of low DO on iron decay rates would mean slower predicted iron removal rates and less DO consumption. A sensitivity analysis was performed to test the magnitude of the impact of including this inhibition mechanism, and the results showed that predicted values varied by less than 0.1 mg/L when the inhibition of iron decay at low DO was included. Sensitivity analysis of other model parameters yielded the following results:

- Varying the assumed reaeration rate: 10% change in predicted results
- Varying the assumed decay and settling rates: 10% change in predicted results
- Varying the assumed flow velocity and channel morphology: 20% change in predicted results

Clearly the model is most sensitive to the assumptions made regarding the hydraulics of Duck Creek. The accuracy of this simplified model analysis is therefore estimated at 0.5 mg/L for reaches where data are available. Under low flow conditions, results will vary and model results may not be as accurate. The assumptions regarding hydraulics were made based on the limited data available and should be verified through more intensive study of the hydrology of the Duck Creek watershed.

Loading Capacity

One of the essential components of a TMDL is identifying and representing the relationship between the desired condition of the stream (expressed as the water quality standard) and pollutant loadings. Once this relationship has been established, it is possible to determine the capacity of the waterbody to assimilate iron loadings and still maintain acceptable DO levels.

It is estimated that 75 percent of the watershed (810 acres) drains to the USGS gaging station at Nancy Street. Duck Creek currently experiences flow losses in the reach downstream of the Nancy Street station, to the point that flow is entirely absent from this reach during certain times of the year. Several management options have been proposed to restore flow in this reach, including lining the streambed to prevent flow losses to groundwater and flow augmentation (Koski and Lorenz, 1999). This analysis assumes that flow is conserved from Nancy Street to the mouth of the creek at Radcliff Road. Although flow conservation does not represent current conditions, it was necessary to assume that no reaches of the creek went dry in order to simulate iron and DO dynamics in the creek. It is not possible to model water quality during zero flow events.

It is also assumed that the seepage of high iron, low DO groundwater occurs only at Taku and Mendenhall Boulevards, the East Fork and Berners Avenue, and that the concentrations of DO and iron in this seepage are the same at all four sites. Table B-2 shows that the iron concentrations at Taku, Mendenhall, and 200 feet below Berners are nearly equivalent (10 mg/L, 9.5 mg/L, and 9 mg/L, respectively.) No iron measurements are available for the East Fork. Since no other data are available, the iron concentration in the creek in proximity to groundwater seepage is therefore assumed to be 10 mg/L, based on the iron monitoring data presented in Beilharz (1998) and Table B-2. That iron concentration corresponds to a DO concentration of 3.2 mg/L (as determined by the regression relating groundwater iron and DO discussed in the Simplified Model Development section). The DO and iron concentrations of the groundwater inflow at Taku and Mendenhall Boulevards are also assumed to be constant year-round. Sufficient data are not available to suggest that the quality of the groundwater varies seasonally (the data in Table B-2 were collected in June 1997, and the wells in Table B-5, were sampled on five dates over a six week period in the spring of 1999.) While the high iron content of groundwater is a natural condition in some parts of the Mendenhall Valley, the inflow of iron to Duck Creek has been increased by stream modifications, including dredging, that have intercepted the glaciomarine sediment layer.

Were sufficient flow records and monitoring data available, the loading analysis would be based on a statistical low flow analysis using long-term average concentrations. The limited flow record is, however, not sufficient to perform a low flow analysis. The loading analysis was therefore done at several flow conditions determined based on the flow percentiles calculated from December 1993 to September 1999 flow record. Based on this flow record, the 10^{th} percentile flow, or flow that is exceeded 90 percent of the time, is 1.0 cfs, and the mean flow is 2.4 cfs.

Using the 10^{th} percentile flow and an initial upstream DO of 7 mg/L, an iron concentration of 10 mg/L at Taku and Mendenhall Boulevards results in a DO concentration below the 7 mg/L criterion and iron concentration above the 0.3 mg/L criterion. The upstream DO was set at 7 mg/L to match the water quality criteria. The iron at Taku and Mendenhall Boulevards must therefore be reduced in order to meet water quality criteria. A reduction to 0.3 mg/L of iron in groundwater resulted in the satisfaction of the DO criterion of 7 mg/L, as shown in Table 3.

The loading capacity for iron in Duck Creek is the total amount of iron that the stream can assimilate without violating the DO criterion of 7 mg/L and the iron criterion of 0.3 mg/L. The loading capacity of each segment can be calculated as the maximum allowable concentration of iron multiplied by the incremental flow increase in each model segment. The total loading capacity for the creek is then obtained by summing the loading capacity of all model segments. Table 4 presents the calculation of the loading capacity for Duck Creek at the critical low flow (10^{th} percentile) of 1.0 cfs. The loading capacity established for the iron and DO TMDLs in Duck Creek is 0.27 tons/yr of iron at low flow.

Table 3. Resulting DO in Duck Creek segments under low flow TMDL conditions

Model Segment	Distance Upstream (ft)	Modeled DO (mg/L)
Taku Blvd	16,600	7.00
Mendenhall Blvd	15,275	7.91
Aspen Ave	14,145	7.86
Duran St	13,650	8.59
McGinnis Dr	12,710	8.95
Stephen Richards Memorial Dr	11,775	9.20
Kodzoff Acres	10,035	9.57
Nancy St	8,520	8.62

Table 4. Loading capacities for Duck Creek under low flow (1.0 cfs) conditions

Model Segment	Distance Upstream (ft)	Incremental Increase in Flow by Model Segment (cfs)	Instream Iron Water Quality Criterion (mg/L)	Low Flow Iron Loading Capacity (tons/yr)[1]
Taku Blvd	16,600	0.158	0.3	0.04
Mendenhall Blvd	15,275	0.289	0.3	0.08
Aspen Ave	14,145	0.004	0.3	0.00
Duran St	13,650	0.002	0.3	0.00
McGinnis Dr	12,710	0.004	0.3	0.00
Stephen Richards Memorial Dr	11,775	0.004	0.3	0.00
Kodzoff Acres	10,035	0.288	0.3	0.08
Nancy St	8,520	0.251	0.3	0.07
Total		**1.000**	**–**	**0.27**

[1] The loading capacity for each segment was calculated by multiplying the flow by the instream criterion. The following conversion factors were used to convert cfs*mg/L to tons/yr:
(28.31685 L/ft^3)*(31,536,000 s/yr)/(1,000,000,000 mg/ton) = 0.893

Wasteload Allocation

Because no point sources contribute to the iron and DO impairment in Duck Creek, the wasteload allocation was set to zero.

Load Allocation

Because instream iron delivered by groundwater is considered the primary source of both iron and oxygen demand, the Duck Creek DO and iron TMDLs establish a loading capacity for iron originating in groundwater inflow. And because there are no point sources and iron is assumed to be the only significant source of oxygen demand, the load allocation (LA) for iron is set equal to the loading capacity. The existing load (EL) is calculated by multiplying the current concentration of iron by the existing flow in each segment, and then summing all of the segments. The current concentration of iron in groundwater inflow from glaciomarine sediments is assumed to be 10 mg/L, with an associated DO of 3.2 mg/L. The groundwater inflow with high iron concentration and low DO occurs in the Taku and Mendenhall Boulevard segments. The groundwater inflow to the remaining segments is assumed to be low in iron (0.3 mg/L) and to have a DO concentration of 5.0 mg/L. Table 5 presents the calculation of the existing iron load for Duck Creek at the critical low flow (10th percentile) of 1.0 cfs. The loading capacity, existing load, load allocation and load reduction under low flow conditions are presented in Table 6. The low flow iron load allocation is 0.27 tons/yr, representing a reduction of
3.87 tons/yr (93 percent reduction) in current iron loads to attain water quality standards for iron and DO under low flow conditions.

As discussed earlier, the delivery and deposition to Duck Creek via storm water runoff may exert an oxygen demand, but that demand is significantly less than the impact of the in-stream iron. Therefore, there is no quantified load allocation for organic material because the sources can not be reasonably estimated. Any contribution to oxygen demand from organic material is considered negligible and can be accounted for through the margin of safety included in the TMDL analysis.

Table 5. Existing iron loads for Duck Creek under low flow (1.0 cfs) conditions

Model Segment	Distance Upstream (ft)	Incremental Increase in Flow by Model Segment (cfs)	Existing Groundwater Iron Concentration (mg/L)	Low Flow Existing Iron Load (tons/yr)[1]
Taku Blvd	16,600	0.158	10.0	1.41
Mendenhall Blvd	15,275	0.289	10.0	2.58
Aspen Ave	14,145	0.004	0.3	0.00
Duran St	13,650	0.002	0.3	0.00
McGinnis Dr	12,710	0.004	0.3	0.00
Stephen Richards Memorial Dr	11,775	0.004	0.3	0.00
Kodzoff Acres	10,035	0.288	0.3	0.08
Nancy St	8,520	0.251	0.3	0.07
Total		**1.000**	**–**	**4.14**

[1] The loading capacity for each segment was calculated by multiplying the flow by the instream criterion. The following conversion factors were used to convert cfs*mg/L to tons/yr:
(28.31685 L/ft^3)*(31,536,000 s/yr)/(1,000,000,000 mg/ton) = 0.893

Table 6. Loading capacity, existing load and load reduction for Duck Creek under low flow conditions

Model Segment	Low Flow Iron Loading Capacity (tons/yr)	Low Flow Existing Iron Load (tons/yr)	Low Flow Iron Load Allocation (tons/yr)	Low Flow Iron Load Reduction (tons/yr)
Taku Blvd	0.04	1.41	0.04	1.37
Mendenhall Blvd	0.08	2.58	0.08	2.50
Aspen Ave	0.00	0.00	0.00	0.00
Duran St	0.00	0.00	0.00	0.00
McGinnis Dr	0.00	0.00	0.00	0.00
Stephen Richards Memorial Dr	0.00	0.00	0.00	0.00
Kodzoff Acres	0.08	0.08	0.08	0.00
Nancy St	0.07	0.07	0.07	0.00
Total	**0.27**	**4.14**	**0.27**	**3.87**

Margin of Safety

This section addresses the incorporation of a margin of safety (MOS) into the TMDL analysis. The MOS accounts for any uncertainty or lack of knowledge concerning the relationship between pollutant loading and water quality. The MOS can be implicit (e.g., incorporated into the TMDL analysis through conservative assumptions) or explicit (e.g., expressed in the TMDL as a portion of the loadings) or a combination of both.

The MOS was included in this TMDL implicitly through a series of conservative assumptions related to both the estimation of the existing loading and the water quality target for the TMDL. The conservative assumptions include the following:

- The assumption that groundwater is the primary source of instream flow in Duck Creek: the contribution of runoff to instream flow could not be quantified. However it is likely that runoff would contain much less iron and more DO than groundwater. The assumption that groundwater is the primary contributor to instream flow is therefore likely to overestimate the iron and low DO contributions to the creek.
- The use of a simple model to simulate the uptake of iron: chemical equilibrium and speciation changes with changes in pH and temperature. Many equilibrium reactions are not first-order so the use of a first-order model could overestimate the uptake of iron and overpredict the oxygen demand. The temperature correction of the settling and decay rates is also a conservative assumption, which would tend to slow the decay rate, extending the length of stream with high iron concentrations.

Seasonal Variation

It is difficult to predict and estimate the annual and seasonal variation in the delivery of iron to and the consumption of oxygen in stream systems. Delivery occurs throughout the year, but can also be influenced by precipitation patterns and their associated infiltration and groundwater discharge rates. As the precipitation infiltrates into the soil and is exposed to the underlying glaciomarine sediments, it picks up dissolved iron and is eventually delivered to the stream as iron-rich groundwater discharge. The consideration of seasonal variation is an important component of the Duck Creek TMDL because of the critical time periods associated with the fishery. These critical periods vary depending on the life stage being considered. The critical period for hatching and fry emergence is from January to May, whereas the critical period for adult spawning migration is from July to November. The TMDL was established with annual allocations of iron to Duck Creek, but the analysis focused on periods of low flow, when the groundwater inflow is more likely to dominate in-stream chemistry. These periods of low flow occur from January through July. The TMDL is therefore sensitive to periods of low flow when exceedances of the DO standard are most likely to occur.

Monitoring and Possible Future Actions

ADEC developed sections describing their expected or potential efforts to measure the accuracy of assumptions made in the TMDLs and effectiveness of the actions taken to reduce iron and increase DO as well as to implement management actions to reduce iron and increase DO in Duck Creek. Those discussions are provided in Appendix E.

Public Participation Process

EPA published a notice on the proposed Duck Creek TMDL for iron and DO in the *Juneau Empire*, the newspaper with the largest circulation in the Juneau area. The public comment period was open from August 15, 2000 to September 15, 2000. Additionally, this proposed TMDL was presented at the Duck Creek Advisory Group's meeting on August 16, 2000. In the published public notice, EPA invited the public to attend this meeting. EPA developed a website, which included the public notice, a fact sheet and the draft TMDL and advertised the website address in the public notice. This website was posted on both EPA Region 10's website and linked from the Alaska Department of Environmental Conservation's website. Additionally, EPA directly sent and e-mailed copies of the public notice and draft TMDL to key federal, state and local agencies, environmental groups and other local organizations.

The Alaska Department of Fish and Game and the City and Borough of Juneau provided comments on this specific TMDL. The responsiveness summary, which discusses how these comments are addressed, is provided in Appendix F.

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Appendix A: Complete List of Dissolved Oxygen Monitoring Stations

Monitoring Station	Distance Upstream (m)	Parameters Sampled	Used in Analysis?	Notes
Dredge Lake	N/A	Coliform	No	Above watershed
Taku Blvd	16,600	DO, Coliform	Yes	
Mendenhall Blvd	15,275	DO	Yes	
Aspen Av	14,145	DO	Yes	
Duran St	13,650	DO	Yes	
McGinnis Dr	12,710	DO	Yes	
Stephen Richards Memorial Dr	11,775	DO	Yes	
Glacier Valley School	11,500	DO	No	Drains to East Fork, Rainbow Rd
Cinema Dr	10,975	DO	Yes	
Kodzoff North	10,600	DO	Yes	
Lakeside Condos	10,575	DO	No	Drains to East Fork
Kodzoff South	10,035	DO	Yes	
Nazerene Pond	9,995	DO	No	
Nancy above East Fork	8,645	DO	No	Samples limit to 1995
Nancy Pond 1	8,620	DO	No	On East Fork
Nancy Pond 2	8,590	DO	No	On East Fork, Stump Lake?
Nancy St	8,520	DO	Yes	At USGS Gage
James Blvd	7,170	DO	Yes	
Tesoro Ditch	7,000	DO	Yes	
Pumphouse	6,800	DO	Yes	
Superbear Pond	6,290	DO	Yes	
Egan Dr	5,490	DO	Yes	
Del Rae Rd	4,370	DO	Yes	
Glacier Hwy	4,150	DO	No	Not enough samples
F.A.A.	3,900	DO	Yes	
Valley Restaurant	3,600	DO	Yes	
Valley Paint	3,300	DO	Yes	

Monitoring Station	**Distance Upstream (m)**	**Parameters Sampled**	**Used in Analysis?**	**Notes**
Professional Plaza	3,000	DO	Yes	
Berners Av	2,701	DO	Yes	
Air Cargo	2,040	DO	Yes	
Airport Blvd	1,050	DO, Coliform	Yes	
Radcliff Rd	0	DO	Yes	

Appendix B: Water Quality and Flow Monitoring Data

1994-1998 U.S. Geological Survey Streamflow Monitoring

Table B-1. Streamflow data from USGS gaging station at Nancy Street (15053200) and precipitation from NCDC Juneau International Airport Station (504100) from 1994 to 1998

Year[a]			**1994**		**1995**		**1996**		**1997**		**1998**	
Annual mean flow (cfs)			3.87		2.65		3.67		3.85		3.75	
Annual runoff (acre-feet/yr)			2,800		1,920		2,660		2,790		2,710	
Annual precipitation (in/yr)			68.89		46.35		60.45		74.62		53.20	
Annual precipitation (acre-feet/yr)			6,200		4,170		5,440		6,720		4,790	
Month[b]	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Flow (cfs)	1.70	2.30	2.52	2.76	2.49	2.00	2.76	3.61	6.72	7.52	3.92	4.31
Precipitation (in/month)	3.27	4.77	4.25	3.10	2.86	3.50	5.43	5.27	8.74	8.27	4.32	6.92

[a] Annual values are summarized by calendar year.
[b] Monthly values are averages for 1994 to 1998.

1997 USDA Forest Service Iron Sampling

Table B-2. Iron in groundwater seepage along Duck Creek (June 1997)

Street Crossing	**Total Iron (mg/L)**	**Temperature (°C)**
Taku Blvd	10	4.2
Mendenhall Blvd	9.5	7.4
Aspen Av	3.5	9.1
Duran St	3.5	9.8
McGinnis Dr	1.5	13.4
Stephen Richards Memorial Dr	0.5	13.8
Below Kodzoff Acres (Kodzoff South)	0.5	15.7
Nancy St (below confluence of East Fork)	2.5	16.9
Del Rae Rd	1	15.6
Berners Av	5	10
200 feet below Berners Av	9	6.6

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

1996 U.S. Geological Survey Water Quality Monitoring

Table B-3. USGS water quality monitoring data

Site	Date	NO_2 (mg/L)	NO_x (mg/L)	NH_3 (mg/L)	TKN (mg/L)	DO (mg/L)
Taku Blvd	8/26/96	<0.01	0.116	0.14	<0.20	4.1
Mendenhall Blvd	8/26/96	<0.01	0.23	0.118	<0.20	6.1
East Fork	9/2/96	<0.01	<0.05	0.044	<0.20	4.6
Cessna Dr	9/2/96	<0.01	<0.05	0.285	0.37	3

1994-1995 Alaska Department of Environmental Conservation Water Quality Monitoring

Table B-4. ADEC water quality monitoring data

Site	Date	NO_2 (mg/L)	NO_3 (mg/L)	BOD_5 (mg/L)	COD (mg/L)
Taku Blvd	10/10/94	3	0.35	<2	14.75
	2/10/95	<0.04	<0.11	3.1	28.06
	5/1/95	<0.04	0.68	3	11.79
Airport Blvd	10/10/94	0.1	0.23	<2	8.85
	2/10/95	<0.04	0.22	<2	5.26
Dredge Lake	10/10/94	0.07	0.02	<2	20.65
	2/10/95	<0.04	<0.11	<2	45.59
	5/1/95	<0.04	0.72	<2	12.23
Rainbow Road	10/10/94	0.84	0.53	<2	22.62
	2/10/95	<0.04	0.38	2	–
	5/1/95	<0.04	1	<2	10.47
Stump Pond	10/10/94	0.05	0.06	<2	2.55
	2/10/95	<0.04	<0.11	2.1	24.55
	5/1/95	<0.04	0.71	<2	9.15

1999 Groundwater Monitoring

Table B-5. Groundwater monitoring for DO and iron

Site	Date	DO (mg/L)	Iron [a] (mg/L)
Well 3 (near Cessna Dr)[b]	4/7/99	4.00	0.6
	4/21/99	7.50	0.2
Well 4 (south of Berners Av)[b]	5/26/99	3.30	0.64
	6/9/99	4.90	-
Well 17 (at El Camino St)	4/21/99	1.30	19.8
	5/5/99	1.20	21
	5/26/99	0.40	8
	6/9/99	1.40	-

Source: Stahl, 1999

[a] Stahl does not mention sample filtering, so assumed to be total iron

[b] Near stream and not considered to be representative of groundwater concentrations.

1994-1997 National Marine Fisheries Service and Alaska Water Watch Water Quality Sampling

Table B-6. Summary of DO monitoring data used in TMDL development

Site	Distance Upstream (ft)	No. of Obs.	Mean	Max	Min	No. of Exceedances	Percent Exceedances
Taku Blvd	16,600	61	5.13	14.60	1.83	48	79%
Mendenhall Blvd	15,275	55	7.58	14.12	4.00	30	55%
Aspen Av	14,145	61	7.72	14.12	5.00	29	48%
McGinnis Dr	12,710	63	8.15	14.94	1.20	17	27%
Cinema Dr	10,975	46	9.07	13.51	6.61	1	2%
Kodzoff Acres	10,600	49	9.55	15.95	4.43	2	4%
Nancy St	8,520	45	7.77	12.77	4.47	20	44%
Superbear Pond	6,290	44	8.36	14.00	3.00	14	32%
Egan Dr	5,490	41	8.43	13.85	1.07	10	24%
Del Rae Rd	4,370	27	8.32	12.54	4.00	9	33%
Berners Av	2,700	48	8.09	13.06	0.61	16	33%
Air Cargo	2,040	38	7.38	13.43	1.08	19	50%
Radcliff Rd	0	19	9.00	14.00	3.00	5	26%

Appendix C: Flow Estimation Method

To use the simplified model to simulate instream DO and iron, it was necessary to have flows for each of the modeled segments. However, flow data are only available at Nancy Street. Information contained in the *Duck Creek Hydrology Baseline Conditions* report (Beilharz, 1998) was used to estimated flows throughout Duck Creek based on the measured flows at Nancy Street. In Beilharz (1998) flows were measured and reported at six locations for six flow regimes varying from low to high flows, and the percentage of total flow that would occur in stream segments was estimated based on the 25-year return interval. The streamflow percentages can be used in flow interpolation for the simplified model segments. Table C-1 lists the six flow regimes, and Table C-2 lists the estimated percentage of flow in each of the stream segments.

Table C-1. Flow measurements in Duck Creek under six different flow regimes

Location	**Low Flow**			↔		**High Flow**
	3/5/96	**5/31/95**	**4/3/95**	**8/16/95**	**8/28/96**	**9/11/95**
Taku Blvd	0.12	0.15	0.13	0.28	0.64	1.03
Mendenhall Blvd	0.34	0.76	0.81	1.15	1.70	2.70
Stephen Richards Memorial Dr	0.35	1.72	1.85	3.37	5.75	14.60
Nancy St	0.76	2.63	3.26	6.77	12.60	25.20
Del Rae Rd	0.00	0.18	1.49	5.44	14.50	22.50
Berners Av	0.00	0.00	0.00	3.36	12.10	25.20

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

Table C-2. Estimated streamflow percentages in Duck Creek

Stream Reach	**Percentage of Total Flow**
Taku Blvd to Mendenhall Blvd	26%
Mendenhall Blvd to Aspen Av	30%
Thunder Mt. Rd to El Camino St	15%
El Camino St to Nancy St	82%
“East Fork” channel	16%
Nancy St to Egan Way	92%
Egan Way to Glacier Hwy	96%
Glacier Hwy to Mendenhall River	100%

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

Although derived for higher streamflows (25-year return interval flows), the percentages of total flow for Nancy Street before and after the East Fork were assumed valid for all flow levels. These are the best available data for estimating the variation in flow along Duck Creek.

Using assorted instantaneous flow measurements from the USGS at several sites along Duck Creek, flow ratios were calculated for Taku Boulevard versus Nancy Street and Mendenhall Boulevard versus Nancy Street. The three ratios for Mendenhall Boulevard versus Nancy Street were 23.5%, 31.3%, and 62.1%. This compares to a 28% ratio (0.26/0.92) for Table C-2. The ratios for Table C-2 are therefore a reasonable assumption for all flows. The flow ratios for Table C-1 are similar.

The simplified model simulation of Duck Creek was limited to the portion of the Creek between Taku Boulevard and Nancy Street, which covers four of the six flow sites in Table C-1. For stream locations not found in Table C-1, the flows were interpolated assuming a uniform variation in flow per unit of stream length. For example, Table C-3 shows the percentage of the Nancy Street gaged flow that occurred on 04/03/95 at each site based on Table C-1. These flow percentages were used in the model for dates where the observed Nancy Street flow was similar to that reported for 04/03/95 in Beilharz (1998). For other flows, a similar flow percentage was calculated and used.

The incremental increases in flow from location to location moving downstream were assumed to come from groundwater. Groundwater inflows between the sites were assigned a DO concentration based on the regression results of the groundwater monitoring data shown in Table B-5. A constant groundwater DO of 5.0 mg/L was assigned for an iron concentration of 0.3 mg/L. An iron concentration of 10 mg/L was assumed in groundwater inflows at the locations where the glaciomarine sediments have been exposed (Taku and Mendenhall Boulevards, the East Fork, and below Berners Avenue). Groundwater inflows at all other points along the stream were assumed to have an iron concentration of 0.3 mg/L based on the water quality standard and data for wells 3 and 4 in the unpublished report by Dr. Randy Stahl at the University of Alaska Southeast. If stream conditions influence the 0.6 mg/L readings at the 2 wells, then the 0.3 mg/L water quality standard is a reasonable estimate in the absence of other data.

Table C-3. Flow percentages at the model segments

Site	Flow Percentage
Taku Boulevard	4%
Mendenhall Boulevard	22%
Aspen Avenue	31%
Duran Street	35%
McGinnis Drive	43%
Stephen Richards Memorial Drive	51%
Kodzoff Acres	71%
Nancy Street	100%

Appendix D: Simplified Model Analysis of Iron and DO Dynamics

As discussed in the Analytical Approach section, a simplified model was developed to simulate flow, iron and DO interactions. This Appendix discusses the specific equations and assumptions used to represent and simulate the processes within the model.

Iron Dynamics

The simplified model assumes that the assimilation of iron through oxidation and floc settling follows a first-order decay rate with stream reaeration. The Streeter-Phelps equation (Chapra, 1997) presented below was used to simulate iron dynamics.

$L = L_0 \exp(-K_{r*}x/u)$

where: L = iron concentration leaving a given stream segment
L_0 = iron concentration entering a given stream segment
$K_r = K_d$ (decay) + K_s (settling) rates
x = length of stream segment
u = flow velocity

A longer stream segment will lose more iron than a shorter segment. Similarly, a segment with a slower flow velocity will lose iron more quickly than a faster-flowing segment. And increased settling and decay rates will lead to faster decreases in iron concentration.

Dissolved Oxygen Dynamics

The simulation of DO dynamics is based on the oxygen deficit, which is the difference between saturation and actual conditons. The following equation was used to calculate DO at saturation:

$D=DO_{sat}$ -model segment DO

$DO_{sat} = \exp(-139.34+1.57E5/T -6.64E7/T^2 +1.24E10/T^3 -8.62E11/T^4)$ (Chapra, 1997)

where: T is temperature in degrees Kelvin, or 273.15 + T °C

The following equation was used to simulate DO dynamics:

$D = D_0 \exp(-K_{a*}x/u) + [K_{d*}L_0/(K_a-K_r)]*[\exp(-K_{r*}x/u) -\exp(-k_{a*}x/u)]$ (Chapra, 1997)

where: D = DO deficit leaving a given segment
D_0 = DO deficit entering a given segment
K_a = reaeration rate
L_0 = iron concentration entering a given stream segment

$K_r = K_d$ (decay) + K_s (settling) rates
x = length of stream segment
u = flow velocity

Similarly to the dynamics of the iron loss equation, a longer distance, slower flow velocity, increased iron floc settling rate, or increased iron decay rate would increase the oxygen deficit, as would a lower reaeration rate.

Reaction rates were adjusted for temperature using the following equation:

$K_T = K_{20} * \theta^{(T-20)}$ where: $\theta = 1.024$ for reaeration and 1.047 for decay and settling.

Simplified Model Calibration and Validation

The simplified model was calibrated using the flow, temperatures, and DO readings from August 18, 1995. The flows for each stream segment were calculated using the 4.2 cfs flow at the Nancy Street USGS flow gage and the flow ratios for August 16, 1995, from Beilharz (1998) and included in Table C-1. The estimated iron concentration at Taku Boulevard from June 1997 (Table B-2) was used as L_0 and the measured DO reading as D_0. The decay, settling, and reaeration rates were adjusted to obtain a good comparison between the model predictions and field conditions. Figure D-1 shows the iron and DO fit for the calibration. Initial reaeration rates calculated using formulae from Chapra (1997) overestimated the DO, so the rate was manually adjusted to obtain a good fit. The simplified model was validated using the data for August 15, 1997, and changing the temperatures, flows, and starting DO. A reasonable fit was obtained for these data, as shown in Figure D-2. All of the formulae used are available in Chapra (1997).

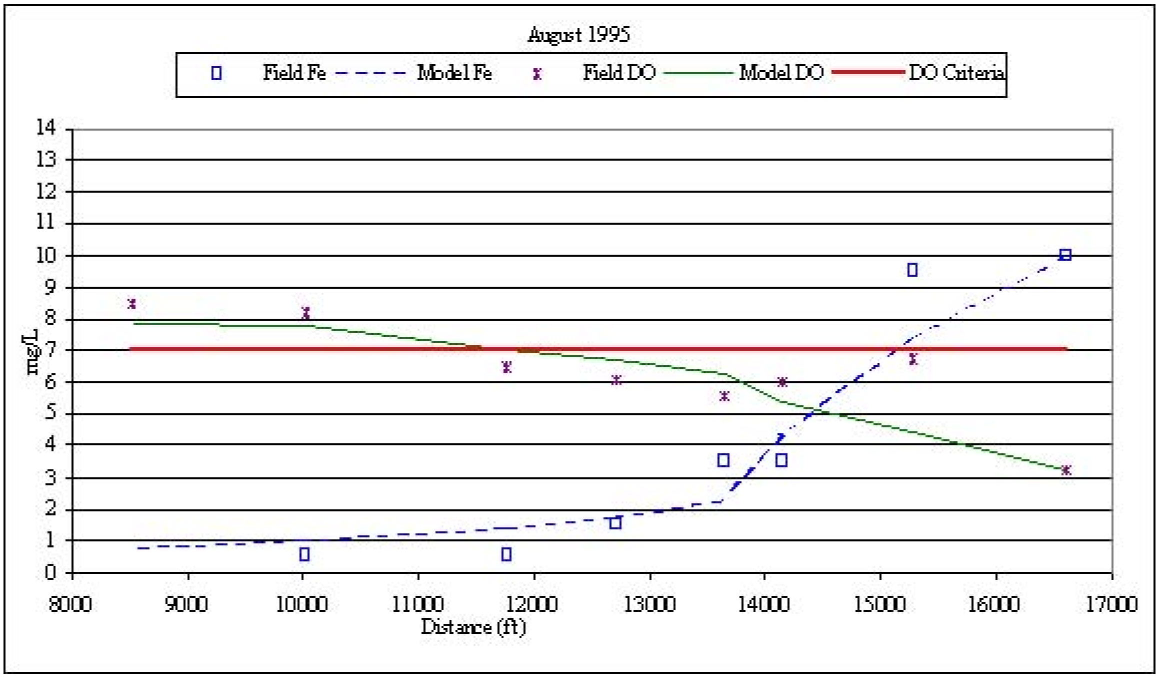

Figure D-1. Calibration of simplified model simulation of iron and DO for August 1995

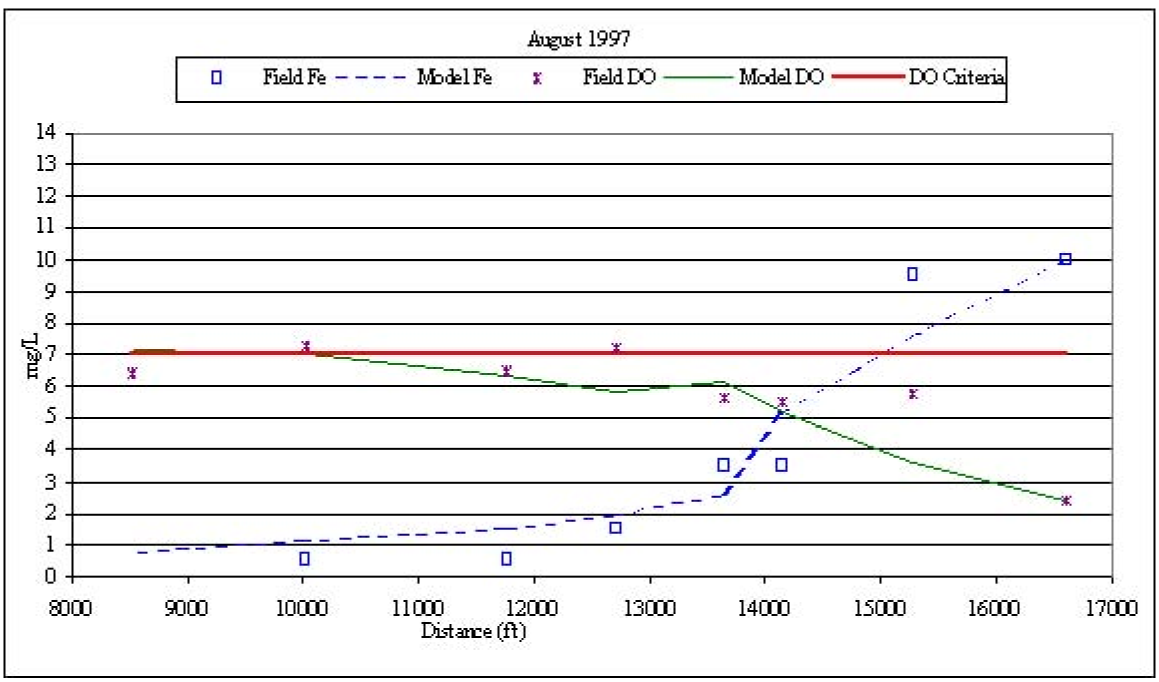

Figure D-2. Validation of simplified model simulation of iron and DO for August 1997

Appendix E: Monitoring and Possible Future Actions

The following sections discuss ADEC's plans for follow-up monitoring for the Duck Creek Iron and DO TMDLs as well as possible future actions for the TMDL implementation, including public participation and education, flow reservations and storm water management.

Monitoring

ADEC developed this section to assist in their efforts to measure the accuracy of assumptions made in the TMDLs and effectiveness of the actions taken to reduce iron and increase DO.

The impacts of dissolved iron and other oxygen-demanding substances on designated uses are difficult to characterize in Duck Creek. For this reason, this TMDL is likely to have significant uncertainty associated with selection of numeric targets representative of the desired in-stream condition and estimates of source loadings and waterbody assimilative capacity. Recognizing this inherent uncertainty, EPA has encouraged the development of TMDLs using available information and data with the expectation that a local commitment to additional monitoring will accompany the TMDL (USEPA, 1991). This approach allows proceeding with source controls while additional monitoring data are collected to provide a basis for reviewing the success of the TMDL. This approach enables stakeholders to move forward with resource protection based on existing data and less rigorous analysis.

The past and current monitoring activities in the Duck Creek watershed are outlined in the water quality analysis section of this TMDL (and in the DCMP). Although the future status of these monitoring programs is uncertain, it is anticipated that water quality and flow monitoring will continue at the USGS sampling stations in the watershed. The monitoring data collected at these sites will provide data that:

- Verify the assumption that nutrients and BOD are not significant sources of oxygen demand compared to iron.
- Assess improvements in water quality.
- Establish the background condition of Duck Creek and its groundwater inflows.

In addition to continued collection of data at the USGS stations, water quality monitoring by other involved state and federal agencies (e.g., ADEC, NMFS) and volunteer groups (such as the Mendenhall Watershed Partnership) should continue in a coordinated manner. The focus of the monitoring programs should be on the assessment of storm water as a COD source, assessment of in-stream conditions (iron and DO concentrations, nutrients, BOD, COD) and assessment of the impacts on water quality of the planned flow restoration and channel improvement activities. The monitoring will provide information on in-stream improvements and show long-term trends. Implementation monitoring is often cited as the most cost-effective of the monitoring types because it provides information on whether restoration efforts are having the desired effect on water quality. Specific projects that potentially affect water quality conditions should be monitored to determine their immediate on-site effects.

A better understanding of surface and groundwater flows in the Mendenhall Valley and Duck Creek would be helpful in the design of restoration and protection actions. Additional data on the hydrology and stream channel characteristics of Duck Creek are needed to determine the effectiveness of the TMDL in meeting water quality standards in Duck Creek. In particular, efforts should be made to measure flow, and channel width, depth and slope at various locations along the Creek under different flow conditions. This information could be used to validate the assumptions made in this TMDL.

Additional information on possible future actions to implement the TMDLs is included in Appendix E.

Possible Future Actions

ADEC developed this section to assist in their efforts to implement the TMDLs for reducing iron and increasing DO.

Public Participation

The Duck Creek Advisory Group (DCAG) was formed in 1993 to plan and coordinate restoration and protection of water quality and fish habitat in Duck Creek and its adjacent wetlands. The DCAG includes representatives of the City and Borough of Juneau, state and federal agencies, private businesses, conservation organizations, and homeowners. While the DCAG provides interagency coordination and addresses technical issues, the Mendenhall Watershed Partnership (the Partnership, www.mendenhallwatershed.org) which was formed in 1998, is a citizen group that provides direction and coordination for protection and restoration projects, public information and education, and volunteer activities throughout the watershed – including Duck Creek. Some of the activities sponsored by the MWP include the following:

- Adopt-a-stream: community groups volunteer to help keep streams in the Mendenhall watershed litter-free.
- Storm drain stenciling: the message “Dump No Waste, Drains to Stream” is stenciled on storm drains to let residents know that waste dumped into storm drains is transported directly to streams without treatment.
- Public education and events: field trips, community forums on important watershed issues, and technical workshops on erosion control and water pollution prevention are organized.
- Youth education: the MWP and Discovery Southeast host “Watershed Discovery Days” for youth to explore, do hands-on science, and help with a stewardship project in the watershed.
- Restoration projects: examples of projects include wetland habitat restoration and stabilization of eroding stream banks.

- Smart development: the MWP has worked with local builders and landowners to prepare user-friendly maps that will help them design their projects with better information about watershed resources.
- Flood control: record flooding in 1998 demonstrated the need for hydrologic studies of the watershed. MWP funding supports the USGS hydrologic studies in the valley.

Public attitudes and perceptions toward the importance of Duck Creek are already changing as a result of the work done by the DCAG and the Partnership, and it is hoped that these organizations will continue their efforts in the future.

Education

Watershed education should include informing the public and development community about the fish and other wildlife that depend on good water quality, the causes of pollution, and the environmental safeguards in place to maintain and restore water quality and fish habitat. In particular, the community needs to understand the effects of land disturbing activities and other sources of pollution on water quality, and to be aware of the local ordinances and other regulations that are in place to prevent degradation of our aquatic resources.

Restoration

Because of the high level of pollution and the substantial loss of aquatic resources in the watershed, a major effort will be needed to restore Duck Creek. The Duck Creek Watershed Management Plan (DCMP, 1999) identifies two areas in which restoration efforts should be focused – water quality and fish habitat. The plan recommends that water quality restoration efforts should concentrate on maintaining flow throughout the stream, creating wetlands to treat storm water, developing riparian greenbelts to serve as stream buffers, and reducing dissolved iron levels in the stream. Specific alternatives include the control of dissolved iron through capping sources of iron with organic fill, planting riparian and aquatic vegetation capable of oxidizing iron, mechanically aerating the water at the sources of dissolved iron, and increasing the volume of flow to dilute the dissolved iron. Fish habitat restoration efforts should focus on the restoration of stream hydrology, including reduced flooding, and increased stream baseflow, and improved stream crossings.

A number of demonstration projects have already been completed, including several improved stream crossings, better snow management, revegetation, sediment removal and channel reconfiguration, and wetland creation. Planned projects include additional stream crossing improvements, wetland creation and riparian zone revegetation, control of dissolved iron, streamflow restoration, streambed lining or sealing, fine sediment removal, and public access and education. The selection and implementation of restoration projects should be balanced with residents' concerns regarding drainage and flood control, while focusing on storm water treatment and wetland management. Education and enforcement of existing regulations will also help curtail the causes of impairment related to drainage and flood control.

Flow Reservations

One way to make sure that there is adequate water flow to maintain water quality and fish populations is through a "flow reservation." The Alaska Department of Natural Resources (ADNR) can allocate minimum flows to protect fish and water quality. Once a flow allocation is granted, water can not be diverted to another use that would reduce flows below the minimum flow reservation. A first step toward the protection of instream flows was initiated by the Juneau Chapter of Trout Unlimited (TU) in 1993, when it filed an application for an instream flow reservation in Duck Creek to sustain fish production and habitat in the creek and its tributaries. This flow reservation has not yet been adjudicated by ADNR, and so it is not known how much of the requested reservation will be granted. An additional flow reservation request could be made to protect water quality and would force adjudication of the 1993 TU request. The prevention of additional decreases in instream flows in Duck Creek is critical for fish habitat restoration.

Storm Water Management

The City and Borough of Juneau Planning Commission recently recommended that the Assembly amend the Comprehensive Plan to include development and implementation of a comprehensive borough-wide storm water management plan. The requested amendment would include discussion of how the lack of storm water management results in an increase in storm flow delivered to streams, and calls for the development of a borough-wide plan that will include:

- A mapped inventory of current storm water discharge points
- An inventory of sediment load and pollutants at each site
- An evaluation of how current standards for public and private development affect water quantity and how they can be improved to help reduce water quantity before storm water enters the storm drain system
- An evaluation of snow management practices

Appendix F: Response to Public Comments

EPA received comments from the Alaska Department of Fish and Game and from the City and Borough of Juneau on the proposed Duck Creek TMDL for Dissolved Oxygen and Iron. This section of the TMDL summarizes the comments received in the letters and provides EPA's response to those comments (Table F-1).

Table F-1. Summary of comments received on Duck Creek TMDL for DO and Iron and their associated responses

Comment	Response
State of Alaska Department of Fish and Game	
1. The proposed TMDL reports should acknowledge that the first step to protect Duck Creek instream flows has been initiated, but not completed. No reservations of water for general water quality or for recreation purposes have been filed to date.	The following text has been added to the Possible Future Actions section of the Duck Creek iron and DO TMDL: "Flow Reservations: One way to make sure that there is adequate water flow to maintain water quality and fish populations is through a 'flow reservation.' The Alaska Department of Natural Resources (ADNR) can allocate minimum flows to protect fish and water quality. Once a flow allocation is granted, water can not be diverted to another use that would reduce flows below the minimum flow reservation. A first step toward the protection of instream flows was initiated by the Juneau Chapter of Trout Unlimited (TU) in 1993, when it filed an application for an instream flow reservation in Duck Creek to sustain fish production and habitat in the creek and its tributaries. This flow reservation has not yet been adjudicated by ADNR, and so it is not known how much of the requested reservation will be granted. An additional flow reservation request could be made to protect water quality and would force adjudication of the 1993 TU request. The prevention of additional decreases in instream flows in Duck Creek is critical for fish habitat restoration." [This text is included in a section developed by ADEC to assist in their efforts to implement the TMDLs.]
2. ADF&G has two instream flow reservation applications pending adjudication by ADNR for protection of fish and wildlife within the Mendenhall River. These two reservations were filed on April 10, 1992 (LAS 13806 and LAS 13807). Impacts to these reservations should be included in the assessment of identifying water sources to augment flows within Duck Creek.	This TMDL no longer recommends flow augmentation as a means of attaining water quality standards in Duck Creek.

Comment	Response
3. The instream flow reservation applications filed for Duck Creek and the Mendenhall River are pending adjudication. Until the adjudication processes for these and other water rights applications are completed, the ultimate amounts of water that ADNR will grant for these water reservations and other out-of-stream water uses will remain unknown.	The following text has been added to the Possible Future Actions section of the Duck Creek iron and DO TMDL: "This flow reservation has not yet been adjudicated by ADNR, and so it is not known how much of the requested reservation will be granted."
City and Borough of Juneau	
4. From page 1 Executive Summary: "…channel modifications and land disturbances near the creek have removed the thick layer of peat that previously filtered out much of the iron," How did a thick layer of peat accumulate in geologically very young glacial valley?	Rephrased as "…channel modifications and land disturbances near the creek, including the removal of the thick layer of peat that previously filtered out much of the iron, have become more common." Both Beilhartz (1998) and Stahl (personal communication) corroborate that the peat layer accumulates very quickly.
5. From page 1 Executive Summary: "…set the loading capacity for iron at 1.36 tons/yr…" In the summary at the top of the page, the loading capacity is listed as 0.23 tons/yr. On page 22, loading capacities are calculated as 0.23 tons/yr (existing conditions) and 1.13 tons/yr (with an additional 3 cfs). Where does the 1.36 figure come from?	This was a typo and has been corrected in the final TMDL. The correct value is 0.27 tons/yr with no flow augmentation.
6. From page 1 Executive Summary: "It is recommended that proposed flow augmentation and streambed lining projects be carried out in order to reduce the inflow of iron to the creek…" Flow augmentation may dilute the iron levels in the stream, but how will it reduce inflow of iron? Similarly, the proposed streambed lining projects are expected to reduce the loss of water from the creek. The water table in these areas is so low that inflow is already minimal in these reaches and thus the projects would have little if any effect on the inflow of iron to the creek.	The text has been changed to read: "The local implementation plan recommends that a combination of the proposed iron reduction and flow restoration projects be carried out in order to reduce the impact of iron inflow to the creek…"

Comment	Response
7. From page 10, 1997 and 1999 Ground water Monitoring: "Two groundwater monitoring wells were found in the USGS data with one reading at each well. Information describing the well locations was not available." If their location is unknown, then so it their relevance. Unless their location can be determined, this information should not be included in the final draft.	The USGS wells are known to be located in Southeast Alaska, but more exact location data were not available. These wells were originally included because they confirm the regional problem of low DO in iron-rich groundwater. The USGS wells have been deleted from the final TMDL because of the uncertainty regarding their locations. An ongoing USGS study of groundwater quality in the Mendenhall Valley may provide valuable information in the future.
8. Page 18, first full sentence: "The turbidity impairment to Duck Creek was addressed in the turbidity TMDL." I have not seen the final version, only an early draft of the turbidity TMDL, but the draft did not mention iron floc as a source of turbidity.	The final turbidity TMDL for Duck Creek mentions iron floc as a potential source of turbidity. Because its contribution to turbidity was several orders of magnitude less than other sources, a loading value for iron floc was not calculated as part of the turbidity TMDL. However, a discussion of the presence of iron floc and its contribution to turbidity was included. A copy of the final turbidity TMDL can be obtained at www.state.ak.us/local/akpages/ENV.CONSERV/dawq/tmdl/fin_tmdl.htm.
9. Page 20, last sentence of first (incomplete) paragraph: "The predicted values are deemed to be sufficiently accurate given the limited amount of iron data available…" According to figure 8 the predicted values for DO are uniformly lower than the observed data in most cases by large amounts. In particular the model predicts DO levels less than the 7 mg/L minimum allowable, while the observed levels exceed this level by about 50%.	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The available data allowed only a very simplified modeling approach. The observed DO values in figure 8 represent supersaturated conditions. In order to simulate supersaturation, the model would have had to include a simulation of algae. Sufficient data were not available to support such a detailed modeling approach. As a result, the model could not simulate the supersaturated DO values seen in Figure 8. However, the model simulates iron and non-super-saturated DO observations well, as seen in Figures D-1 and D-2.
10. Page 20, last full sentence: "This anaylsis assumes that flow is conserved from Nancy Street to the mouth of the creek at Radcliff Road." While the model may not work if the flow stops entirely, it should be able to handle a decreasing flow. This appears to be a reality of Duck Creek in all but the highest of flows according to Table C-1, in particular during the situations when DO is at it's lowest.	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The section of Duck Creek that was modeled ran from Taku Boulevard to Nancy Street. The sections of Duck Creek that are losing flow are below this point, and water loss is not consistent at all flows, which would be difficult to model given the sparse data available. The approach taken was conservative and appropriate given the available data because it focused on low flow conditions when the creek is most susceptible to losing reaches.

Comment	Response
11. Page 22, second paragraph: "The accuracy of this simplified model analysis is estimated at 0.1 mg/L." None of the charts comparing the model's output to actual measured conditions come close to having this degree of accuracy. The model is off by several mg/L in figure 8, approximately 1 mg/L in Figure D-2 and even in the calibration trial Figure D-1, the predictions are more than 0.1 mg/L from the field measurement at half of the stations. If the model actually did predict DO to within 0.1 mg/L it would be a useful tool indeed, but if Figure D-2 (or Figure 8) is representative, it's usefulness at this time is questionable.	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The assumption of iron following an exponential decay creates an error in the DO that can not be precisely quantified. The accuracy of the model equations is estimated at 0.1 mg/L. However, uncertainty associated with reaction rates and other variables means that the error is likely larger. The model is believed to simulate the system as accurately as possible with the available information. The use of first order reaction rates represents a conservative assumption that accounts for some of the model error. First order rates could overestimate the uptake of iron and overpredict the oxygen demand.
12. Page 21, Second paragraph from the bottom: "Decreasing both the groundwater and headwater iron concentrations to 0 mg/L still resulted in a exceedence of the DO standard at Duran Street…" This suggests that the model is flawed. What seems to be happening in the model is that even without iron problems, the 2 mg DO/L groundwater isn't being aerated as fast as it is being put into the creek. In actual practice, the 50th percentile flow will be a combination of groundwater (at an estimated 2 mg DO/L) and surface runoff (nearly saturated with DO).	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The model assumes that all inflows to the creek are from groundwater, and ignores surface water inputs. While surface runoff is likely to contribute to instream flow, more data are needed to allow simulation of reach-variable reaeration. In addition, the assumption that groundwater is the primary source of flow represents a conservative assumption that contributes to the TMDL's margin of safety.
13. Page 22, Load Capacity Calculations: The Loading Capacities (0.23 tons/ yr under existing conditions and 1.13 tons/yr with an additional 3 cfs) have been calculated from a constant iron concentration of 0.3 mg/L (apparently determined by the reaeration rate based on the 10th percentile flow). This is only accurate for the entire stream if the reaeration rate does not vary with the differing flow levels that are found in different parts of the stream.	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. 0.3 mg/L is the secondary drinking water standard and the applicatble water quality criterion for iron and was therefore used as the TMDL target.

Comment	Response
14. Page 23, Load Reduction Calculations: The existing load (EL) figure appears to assume that the entire flow is made up of high iron, low DO groundwater. This is not the case. As mentioned above, some of the flow will be iron-free high-DO runoff, and in the case of the augmented flow, the additional 3 cfs will also be low-iron water. The addition of 3 cfs of iron-free water will allow the 0.76 cfs of 10 mg/L water to dilute to the point where less of the iron will have to be removed. (Perhaps the additional water will also reduce in more turbulent flow, resulting in an increased reaeration rate.)	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The flow augmentation was assumed to contain 0.3 mg/L iron and 7.0 mg/L DO as a conservative assumption. It is likely that the flow used to augment Duck Creek would have a lower concentration of iron.
15. Page 30 Table B-2: Two hundred feet below Berners Avenue is near the site of the new arch-pipe culvert at Cessna Drive. Construction of this culvert involved "mechanically deepening" the channel in the vicinity of the culvert. According to table B-2 and the first sentence on under the heading 1997 USDA Forest Service Iron Sampling, on page 8, this should have resulted in iron-rich groundwater entering the stream. This was not the case. I was present when a female Forest Service employee tested the upwelling ground water for iron during construction of the culvert. The ground water had barely detectable amounts of iron, significantly less than the stream water. This is consistent with iron readings taken from well 4 as listed on table B-5.	The problem of high iron inflows into Duck Creek is very scattered spatially. The available sources of data indicate that high iron occurs at this location (Table B-2). The conservative assumption of high iron contributes to the TMDL's margin of safety.

Comment	Response
16. Page 32 Table B-6:It appears from this table that DO levels start falling downstream of Egan Drive, particularly between Berners Ave. and Air Cargo. As elsewhere in Duck Creek iron-rich ground water has been the cause of low DO, one might assume that it is again the cause in this reach. Indeed this is the conclusion that Beilharz (1998) reached (Second and third sentence of first full paragraph on page 18). A little more thought on the matter though leads one to a different conclusion. First, according to Table C-1, only at extreme flows, does the creek gain water (iron-rich or otherwise) in this reach. Indeed during low flows it is typically dry around Berners Ave. I personally was responsible for taking much of the data that is summarized in table B-6. Note the low number of observations in the lower creek. Obviously, when there was no water at a given site, no data was collected on that day. However, if there was any water, even a standing pool (as was often the case at Berners Ave and Air Cargo) data was collected. While not mentioned in Table B-6, these standing pools were generally very warm (reducing the oxygen saturation level) and often had algae or decaying plant (or sometimes) fish matter in them. For a truer picture of the DO levels in this portion of Duck Creek one should look only at the observations taken when Duck Creek was flowing. (probably the times that Del Rae and Radcliff both had water- The latter is occasionally tidally influenced.)	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The available data allowed simultion of iron and DO only in the portion of Duck Creek upstream of the Nancy Street flow gage. Egan Drive is downstream of Nancy Street and therefore beyond the modeled area. The description of algae and decaying organic material was not available in any of the data sources.
17. Page 34 Table C-2: How does the El Camino to Nancy St flow (82%) plus the East Fork Channel flow (16%) combine to make the Nancy St to Egan Way (sic) figure of 92%?	These numbers were taken directly from Table 7 of the *Duck Creek Hydrology Baseline Report* (Beilharz, 1998). This was the only information available on the distribution of flow along the creek. Additional monitoring would be useful in verifying this information.
18. Page 34 last partial paragraph: "Although derived for higher stream flows, the percentages of the total flow for Nancy Street and after the East Fork were assumed valid for all flow levels. These are the best available data for estimated the variation in flow along Duck Creek." Both statements seem to ignore Table C-1.	A section entitled "Limitations of the Iron and Dissolved Oxygen Model" has been added to the TMDL and describes the model in more detail. The simple model used required a consistent, uniformly increasing ratio. The flows in Table C-1 give extremely variable ratios that are valid only for the listed flows. The percentages in Table C-2 are the best available, uniformly increasing ratios which can be applied to all flow scenarios.

Comment	Response
19. Page 35 Fourth sentence of first entire paragraph: "Groundwater inflows between the sites were assumed to have a DO of 2 mg/L based on the groundwater monitoring shown in Table B-5." Actually table B-5 shows an average DO level of 2.64 mg/L if each well (rather than each reading) is given equal weight. The DO levels of the wells known to be near Duck Creek averages 3.64 mg/L	The following regression relating groundwater iron concentrations to groundwater DO concentrations was developed based on the data presented in Table B-5: [DO] = -0.187*[Fe]+5.0397 (R^2 = 0.6315) Therefore, for [Fe] = 10 mg/L, [DO] = 3.2 mg/L and for [Fe] = 0.3 mg/L, [DO] = 5.0 mg/L
20. Page 35 Table C-3: What are the units of velocity? Also, even taking the side slopes (2:1 H:V or V:H?) into account, the velocity doesn't seem to scale with cross-sectional area.	Table units are ft/sec and have been added to the final document. All velocities are calculated based on Manning's equation: Velocity = (1.486 / Roughness) * (Area / Wetted Perimeter)$^{2/3}$ * (Stream Slope)$^{1/2}$
21. On to the computer model. As given, the model is a steady-state model. In particular, while the model does note the rate of iron settlement (Ks), it does not keep track of the amount of settled iron. The model assumes that the rate of iron settlement is equal to the rate of decay of settled iron. It is not clear that this is appropriate. In particular, in the lower creek, iron floc is not consistently present. High water tends to remove, either directly (as described on page 103 of Thomann 1972) or by presenting enough DO to allowing for complete decay, the iron floc.	Settled iron is considered adsorbed to sediment and no longer available for decay. It is assumed that storms will flush this adsorbed iron out of the system. A full DO/metals/sediment model would be required to allow settled iron to resuspend and exert an oxygen demand. Sufficient data are not available to support a full DO/metals/sediment model. The use of first order reaction rates is a conservative assumption that could overestimate the uptake of iron and the associated oxygen demand.
22. The Streeter-Phelps Equation near the top of page 36 makes sense mathematically, but Kd (the iron decay constant) should dependant on the availability of DO. Unlike Ks (the settling rate) it is not a fixed constant. Assume the dependence is linear with DO, a more appropriate equation would be something like: L = Lo exp(-Ks x/u) exp(-Kd (DOsat - D) x/u) Where Kd is the iron decay rate at unit oxygen concentration.	The Streeter-Phelps equation considers the balance of iron decay versus settling. The model is an approximation of iron and DO dynamics. The introduction of a dependence of the decay rate on available oxygen would introduce so much error into the model as to make it unusuable.

Comment	Response
23. The equation cited from Chapra on page 36 , regarding the relationship between saturation levels of DO and temperature appears to be in error. This equation has a local minima around T=293. it should be monotonically decreasing for all reasonable temperatures. Equation 5-10 in Thomann 1972 gives this relationship as: cs = 14.652 -0.1022T + 0.0079910T^2 - 0.000077774 T^3 where cs=DOsat in mg/l and T is temperature in degrees C. (Note that there is a typo in Thomann. the coefficient on the last term should be 7.7x10^-5 as given above, not 7.7x10^-4.)	This equation is in Chapra (1997), Qual2E, and *Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling* (USEPA, 1985). Table 3-2 (page 93) of *Rates* has the saturation values for 0 to 40 degrees C and no minima occur. The approach taken was the most reasonable given the information available.
24. Similar to point 24, the second equation from Chapra (page 36 of the TMDL) also seems to assume that the decay of the iron is limited only by the availability of iron, without regard to DO.	This is the classic Streeter-Phelps DO deficit equation and represents deficit reduction through reaeration and deficit increases through decay. Although it seems possible that decay could be retarded at low DO, there is no available literature regarding the decay of iron at various DO levels. Therefore, such decay is not accounted for in the model.
25. The top of page 37 gives a formula for adjustment of reaction rates with temperature. The same adjustment is given for both the decay and settling of iron. The decay is a chemical process, the settling a physical one. It seems unlikely that both processes would be affected by temperature in the same manner. I'm not sure about the chemical process, but the settling should be proportional to terminal fall velocity with is proportional to 1/kinematic viscosity. The latter does not follow the 1.047 ^(T-20) very closely.	Use of the kinematic viscosity and fall velocity would require a complex model which includes particle sizes to develop fall velocities. For a simple model, including Qual2E, the use of the temperature correction is accepted practice.